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Effect of Wind Variation on Distribution Pattern of Slow Revolving Sprinkler Heads

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EFFECT OF WIND VARIATION ON DISTRIBUTION PATTERN OF SLOW REVOLVING SPRINKLER HEADS

By

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This is to certify that, in accordance with the requirements of South Dakota State College for the Master of Science Degree, Mr. John L. Wiersma has presented to this committee three bound copies of an acceptable thesis, done in the major field; and has satisfactorily passed a two-hour oral examination on the thesis, the major field, Agricultural Engineering, and the minor field, Civil Engineering and Agronomy

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INTRODUCTION

Sprinkler irrigation has been practiced for the last several decades; it is not a new or special method of irrigation. Its use on other than specialized and garden crops has spread very rapidly during recent years. Several factors may have helped bring about this change. Some of the more important ones are:

1. The realization of the detrimental effects of short drought periods during the growing season even in comparatively wet years.

2. The availability of improved portable irrigation equipment.

3. The desire of farmers to eliminate weather risks in the production of high income farm products.

4. News articles on Missouri River Basin Development.

On many existing irrigation projects, established irrigation farmers wish to install sprinklers in order to improve their irrigation application, conserve water and to adjust their practices to improved cropping methods and more convenient working hours. On many of the new proposed irrigation projects in the North Central States, irrigation by sprinklers is considered the best and perhaps the only feasible method of water application. Special soil conditions, topography, or crop requirements cause other methods to be impractical. Sprinkler irrigation helps to minimize water seepage problems. A typical installation is shown in Figure 1.

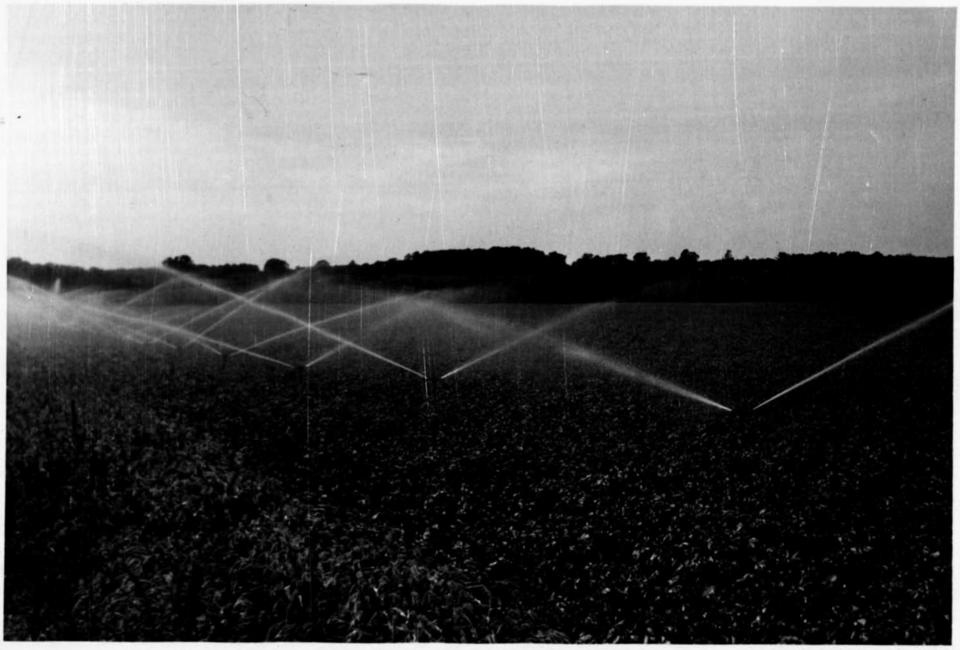

Figure 1. A Typical Sprinkler Installation.

Figure 2. Poor Water Distribution Caused Uneven Seed Germination

G. W. Lineweaver, of the Bureau of Reclamation, has published the following statement:

> Of the many thousands of acres of land in the Missouri-Souris and Missouri-Oahe unit of the Missouri River Basin project of the Bureau of Reclamation in the Dakotas, large portions may be irrigated by sprinklers that cannot be successfully irrigated by surface methods. Also in portions of the units, much larger percentages of the land may be irrigated by sprinkler than by surface methods. This land is in a glaciated area topographically unsuited to surface irrigation. The proportion of these units that may come in these classifications cannot be intelligently estimated until the surveys now being carried on are completed. On other projects considerable areas come under this category.[1]

Sprinkler irrigation has a significant place in bringing about improved use of our resources. Increased financial success may result where conditions do not lend themselves to surface methods of irrigation. On the other hand, if sprinklers are used where insufficient information is available on design, the results may be impractical and unsuccessful. Under these conditions many farm installations may operate at a financial loss. Figure 2 shows the resultant effect of poor practice. This crop, sprinkler irrigated to help germination, has bare spots where insufficient moisture was available for germination. This was caused by poor distribution of water.

In a published statement by G. W. Lineweaver, of the Bureau of Reclamation, the following statement was made:

> There are a number of problems in connection with sprinkler irrigation which should be made the subject of re-

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[1]Sprinkler Irrigation. Bureau of Reclamation. Dec. 1949. p 9.

search. Some of these problems have been studied in a limited way but the information so far secured is far from complete. The following tabulation covers the more important items. The asterisks mark those whose solutions is most pressing:

*1. Evaporation Losses.

...

2. Effect on crops.

...

3. Effect on soils.

...

4. Equipment.

*a. To what extent and how can the distribution pattern of individual and groups of sprinklers be improved?

1. Effect of wind.

...

5. Use.

*a. What irrigation efficiency can be expected with sprinklers under different conditions?

1. Effect of wind.

b. Can over-all savings in cost be achieved by changes in design, perhaps by using higher pressures and wider spacing?[2]

According to an investigation made by the writer, the average wind velocity during the irrigation season at Huron, South Dakota is 10.8 miles per hour.[3] This average was taken from reports that included data taken over a period of 52 years. This average included all hours of the day. The investigation also indicated that the wind velocity is greatest from the hours of 2 P. M. till 4 P. M. Therefore, the following

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[2]Sprinkler Irrigation. Bureau of Reclamation. Dec. 1949. pp 59 - 60.

[3]The irrigating season is from April 15 to October 1.

conclusion can be made -- during many hours of sprinkling time a wind velocity of greater than 10.8 miles per hour will be encountered.

In the past sprinkler designs were made on the basis of a four mile per hour wind velocity or less.

The writer believes that his time and effort has been well spent in making a study of the effect of wind on the sprinkling pattern, which in turn is directly related to irrigation efficiency.

WORK OF OTHER INVESTIGATORS

Many tests have been made to determine uniformity of distribution. Generally manufacturers have facilities for testing their own sprinklers and for making necessary adjustments. Numerous factors other than wind, such as pressure, spacing, uniformity of rotation of sprinkler, ratio of size of range nozzle and spreader nozzle and other factors enter in on uniformity of distribution.

Probably less has been done on the effect of wind than on any other factor because most sprinkler installations in the past have been in areas of relatively low wind velocities. The Rainbird Sprinkler Manufacturing Corporation has published the following statement:

> One of the most important preliminary design factors is to consider the wind. Always run the lateral lines across the wind. This puts the sprinklers closer together and helps to compensate for the wind. If higher than four miles per hour winds are encountered it may be necessary to use twice as many sprinklers. Where a 40 foot spacing is usually used, you may have to put sprinklers every 20 feet on the lateral. In doing so reduce the gpm discharge per sprinkler to half the amount and you will maintain the same precipitation rate as with the 40 foot spacing.[4]

F. E. Staebner has run a series of tests on many different makes of sprinkler heads. In conducting his tests 112 cans used as rain gauges were distributed in a geometric pattern over the sprinkled area to catch the water as it fell. The water was measured volumetrically to determine amount of water falling in each section. No particular emphasis

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[4]Gray. Sprinkler Irrigation Handbook. Rainbird Sprinkler Mfg. Corporation. 1948. p 9.

was placed on wind disturbances of the pattern. During the time he was doing his work, as well as at present, some manufacturers and experimenters have been striving for a sprinkler that distributes a uniform amount over a large portion of the area covered, with a rather abrupt breaking off at the edges. Others have given more consideration to the effect of overlap and have tried to obtain a different pattern. Staebner judged the sprinklers tested on their ability to distribute water so that the maximum depth was not more than twice the minimum depth, except near the edges of the area covered, but he did not discuss the question of overlap nor of proper spacing for such sprinklers. He states, "No matter how successfully they may distribute water over a circular area, they leave much to be desired, because if circles just touch one another a considerable area is left unwatered, and if they overlap a great amount of double coverage results."[5] He further concludes, "More uniform distribution over a large area can be obtained with the overhead-pipe system (nozzle lines) than with any other type of spray irrigation equipment."[5]

In the Handbook of Engineering Practices for Region 7[6], published by Region 7 Soil Conservation Service the following recommendation is made:

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[5]Staebner, F. E. Tests of Spray Irrigation Equipment. U. S. Dept. of Agr. Cir. 195: 1931. p 29.

[6]Region 7 is comprised of the Pacific Coast States.

> Where wind velocities range between 5 and 15 miles per hour, maximum spacing should be reduced to 0.5 of the wetted diameter. Where wind comes from a definite prevailing direction, laterals should be laid at right angles to the wind direction and the spacing on the lateral reduced to 0.2 to 0.3 of the wetted diameter.[7]

The sprinkler tests conducted by J. E. Christiansen at Davis, California were carried on to obtain definite information about the distribution of water under various conditions, and especially to determine the effect of wind, speed of rotation, and spacing of sprinklers on distribution. In his first 122 tests small rain gauges made from number 2 1/2 tin cans were placed 10 feet apart in each direction over the entire area covered by the sprinkler except on the north-south and east-west axes, which were five feet apart. For the remainder of the tests an additional can was placed in each square -- one being provided for each 50 square feet.

A domestic water system furnished water at 40 pounds per square inch pressure. A booster pump was used for higher pressures. A standard Weather Bureau type four-cup anemometer was used giving wind velocity at a point about 10 feet above the ground.

A total of about 130 tests were run on slow revolving sprinklers using these facilities. Lawn sprinklers and whirling sprinklers were also studied. The water caught in the rain gauges was measured to the nearest cubic centimeter.

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[7] Handbook of Engineering Practice for Region 7. Region 7 Soil Conservation Service 1947. p VI - 17 (I - 6)

A numerical expression to serve as an index of uniformity was developed. For this purpose the following expression was used:

$$C_u = 100\left(1 - \frac{\Sigma x}{m\ n}\right)$$

C_u is the uniformity coefficient expressed as a percentage, x is the deviation of individual observations from the mean value m, and n is the number of observations.

An absolute uniform application would then be represented by a uniformity coefficient of 100 per cent.

Table I is a summary of data taken from Christiansen's average uniformity coefficients for several tests on the same sprinkler under similar conditions. In this table the distance S_2 represents the distance between sprinkler lines. The distance between sprinklers on the line is 10 feet throughout the entire table.

It is noted that only in the second series of tests is the wind velocity average greater than 10 miles per hour.

TABLE I*

TABLE 15

SUMMARY OF DATA IN TABLE 14 GIVING AVERAGE UNIFORMITY COEFFICIENTS FOR SEVERAL TESTS ON THE SAME SPRINKLER UNDER SIMILAR CONDITIONS

Sprinkler	Test no.	Average wind, miles per hour	Average pressure, pounds per square inch	Average rate of rotation, revolutions per minute	Average diameter of pattern, feet	Average uniformity coefficient, in per cent, for various spacings between sprinkler lines, S_2								
						20 feet	30 feet	40 feet	50 feet	60 feet	70 feet	80 feet	90 feet	100 feet
A-1	3, 4	2.1	46	1.3	102	96	91	91	92	88	85	75	..	...
B-1	8, 9, 10, 57, 58, 59	14.0	40	...	96	98	95	88	85	84	78	67	..	...
B-1	6, 13, 55, 56	8.0	42	1.1	100	98	96	89	86	88	81	70	57	...
B-1	7, 14, 15, 16, 17, 54	3.1	38	0.5	118	99	97	95	90	85	88	90	83	73
B-2	22, 23, 24, 36, 37, 39, 67, 68	1.7	41	1.8	111	98	95	93	89	81	82	87	86	78
B-2	12, 19, 20, 38	4.5	40	3.4	102	98	94	92	83	84	89	83	70	...
B-4	132, 133, 134	3.2	40	0.2	109	98	94	93	91	92	89	79	...	...
C-1	26, 28, 135, 136	2.0	41	1.6	122	97	98	95	95	87	87	90	90	81
C-1	27, 137, 138, 139	6.7	40	1.0	109	98	97	93	86	86	90	85	72	...
F-1	85, 86, 89, 90, 91	3.8	35	1.2	105	97	93	93	87	82	84	85	76	...
F-1	83, 84, 87, 88	9.3	38	1.4	94	97	93	89	84	87	83	71	...	...
G-1	97, 98, 99, 170	3.4	35	0.2	116	97	97	96	96	94	91	83	70	...
G-1	96, 100, 101, 169	8.6	35	0.2	109	98	97	94	89	90	86	74	62	...
G-2	163, 164, 166	2.2	37	...	107	98	96	93	87	89	90	77	...	...
I-1	109, 113, 114, 115, 117	3.5	42	1.3	112	97	96	93	88	87	86	81	70	...
I-1	107, 108, 110, 111, 112	9.9	42	1.5	98	98	96	85	85	84	74	60	...	...
J-1	119, 120	3.3	35	0.6	100	97	97	96	91	92	86	74	61	...
J-1*	121, 122, 123	4.3	50	0.8	116	97	97	90	93	92	87	78	...	...
J-2	125, 126	9.4	50	1.7	107	98	97	89	85	90	91	76	...	...
L-1	103, 104, 106, 145, 146, 147, 148	3.7	42	2.0	113	97	96	93	86	84	83	78	69	...
M-1	141, 142, 143, 144	2.7	47	1.0	128	99	98	95	92	89	85	87	88	[illegible]
P-2	93, 94	2.6	34	...	105	94	92	93	90	91	90	82	70	...
B-2†	129, 130	3.1	50	0.3	120	98	97	92	87	81	83	88	85	...

*Main nozzle from sprinkler L-1.
† Nozzle angle, 14°.

*Christiansen, J. E., Irrigation by Sprinkling. Calif. Agr. Expt Sta. Bul. 670. 1942. p 106.

ANALYSIS OF THE PROBLEM

Before an analysis of actual field sprinkler patterns is made an analysis of typical geometric patterns will aid in determining desirable field patterns. The typical distribution pattern shown in Figure 3 is a pattern as it might appear if no disturbing factors were present. The pattern from one sprinkler head is triangular in shape and with the overlap from adjacent heads a nearly uniform application would result.

If under the same favorable conditions a wind were present to disturb the pattern a typical wind blown pattern such as is shown in Figure 4 might result. The same general pattern exists with the exception that the triangle is considerably larger on one side of the sprinkler head. It can also be noted that there is a tendency for a heavy concentration of water near the sprinkler head. The uniformity coefficients for these two conditions are shown in Table II.

Not all geometric patterns are triangular. Figure 5 illustrates some of the other patterns that may be encountered. The uniformity coefficients are shown in the graphs, with spacing indicated in per cent of diameter. The spacing between heads on the line is equal to 5 per cent of the diameter. The distribution for pattern B is nearly uniform for all values of S_2 up to 55 per cent of the diameter. Patterns A and C give fairly uniform applications for all spacing up to 65 per cent of the diameter; beyond this the uniformity drops off rapidly. Pattern D

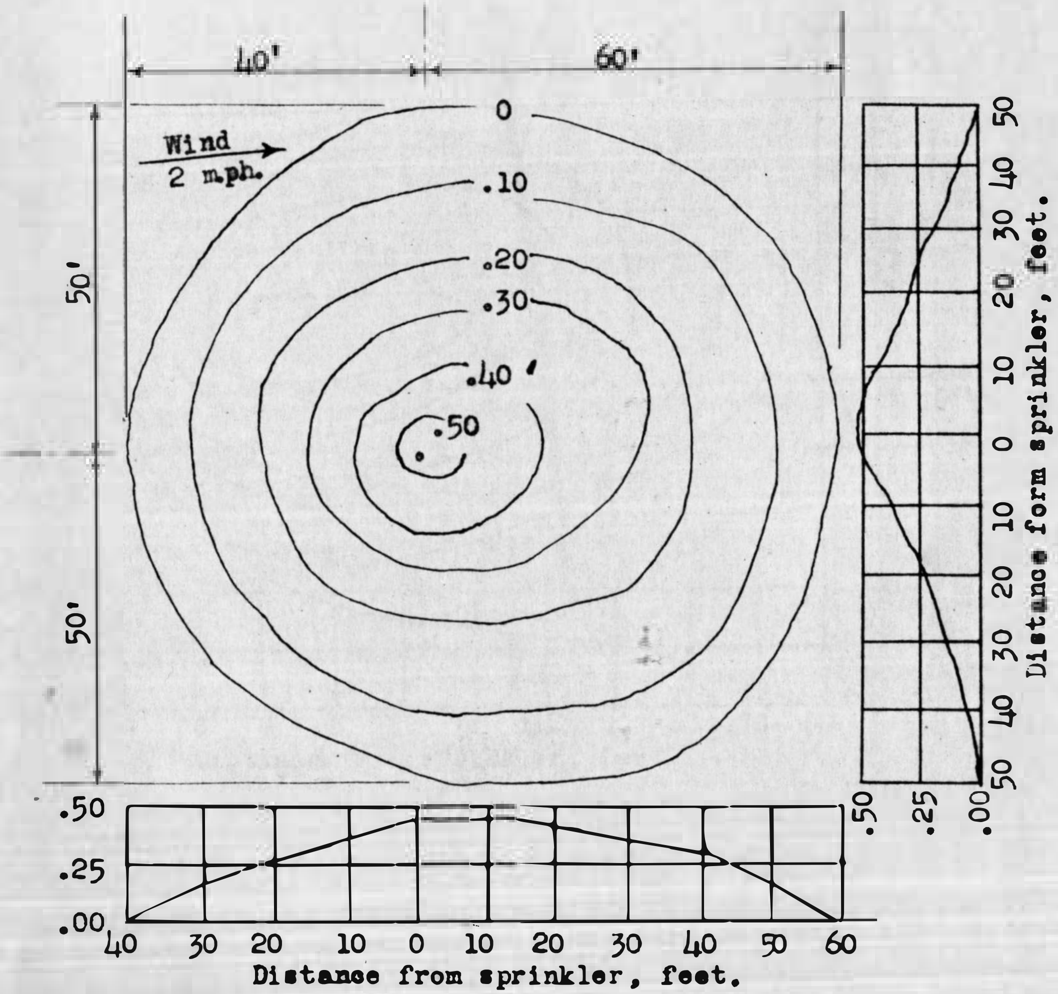

Figure 3. Typical Pattern Under Favorable Conditions

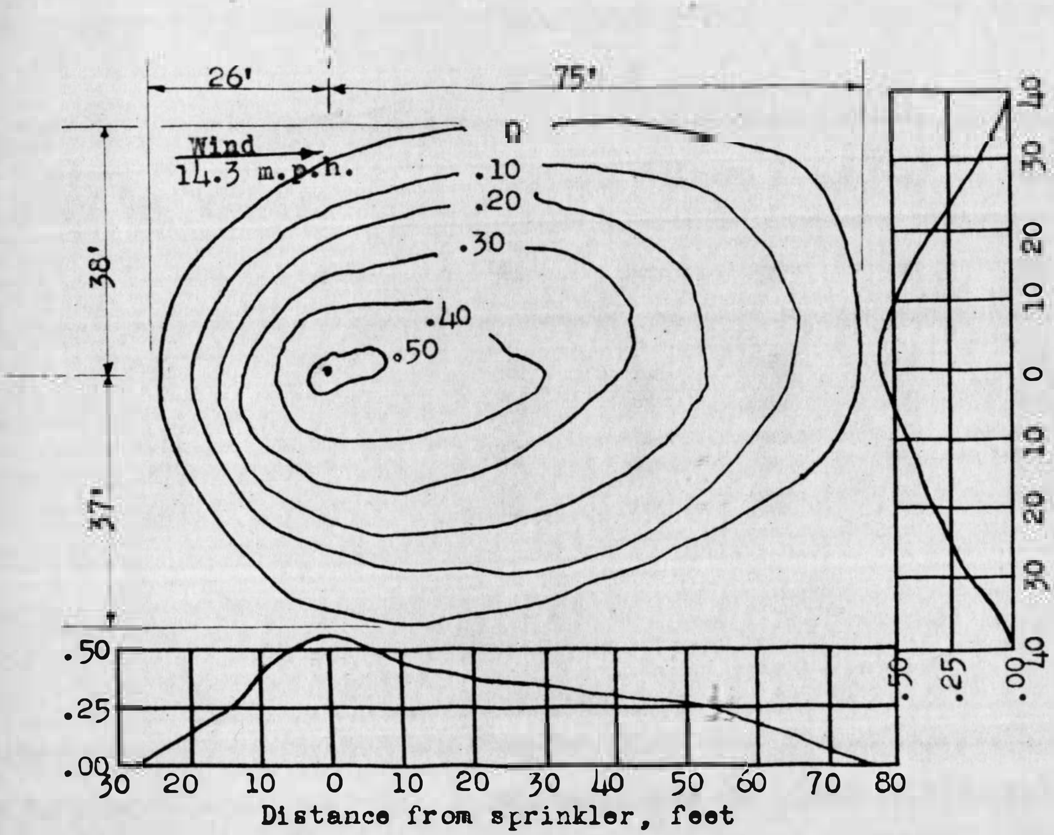

Figure 4. Typical Pattern Under Windy Conditions

TABLE II

PATTERN UNIFORMITY COEFFICIENTS FOR VARIOUS LATERAL LINE AND LATERAL MOVE SPACINGS OF PATTERNS SHOWN IN FIGURES 3 AND 4

Figure 3

Spacing Between Heads (S_1) in Feet	Spacings Between Lines (S_2) in Feet				
	30	40	50	60	70
10	97	96	95	91	88
20	95	95	90	89	85
30	94	94	90	87	82
40	94	92	89	86	79
50	92	90	88	84	73

Figure 4

Spacing Between Heads (S_1) in Feet	Spacings Between Lines (S_2) in Feet				
	30	40	50	60	70
10	90	90	83	64	57
20	89	89	82	64	53
30	88	87	31	63	50
40	82	80	76	60	43
50	80	76	72	57	37

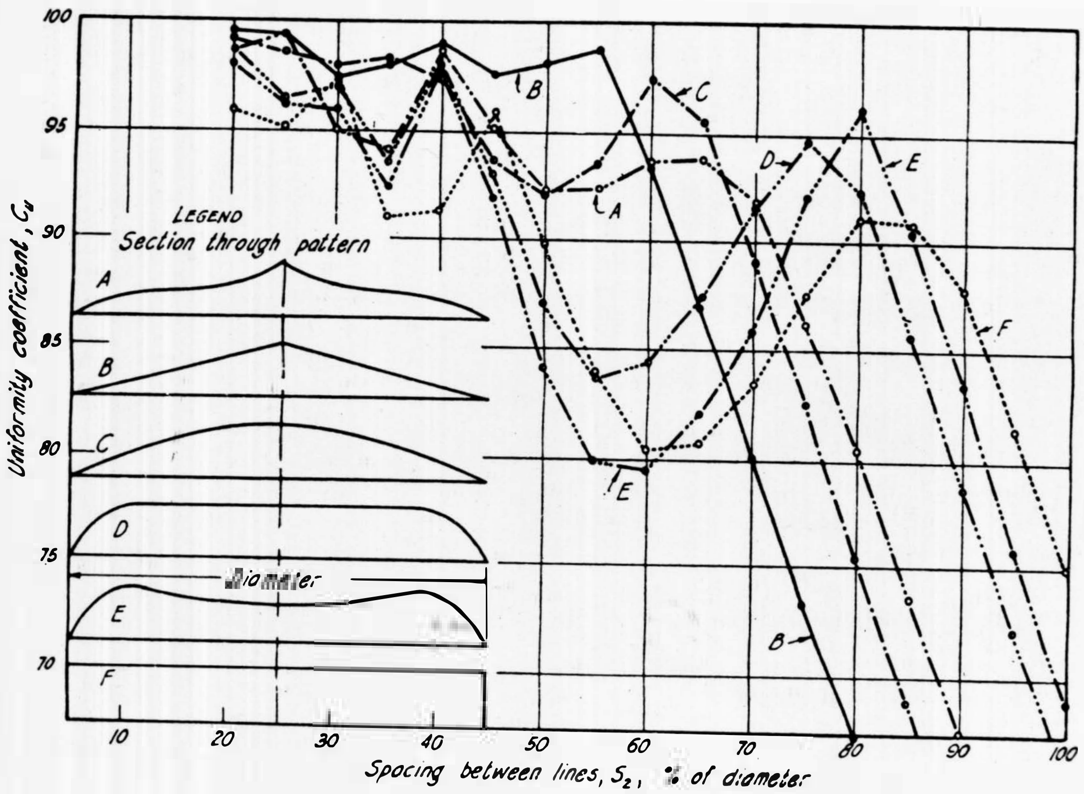

Figure 5*. Uniformity Coefficients for Geometric Patterns.

*Christiansen, J. E., Irrigation by Sprinkling. Calif. Agr. Expt. Sta. Bul. 670. 1942. p 96.

produces a fairly uniform distribution for spacing of 75 per cent; but for spacing of 45 to 75 per cent there is an appreciable variation.

For economic reasons a pattern similar to A, B, or C is desirable because sprinklers are usually spaced as far apart as possible in either a square or equilateral triangle arrangement.

Several known factors can distort the distribution pattern. Some of the more important ones are:

1. Excessive wind velocity.
2. Angle of wind with respect to lateral line.
3. Uniformity of rotation.
4. Speed of rotation.
5. Combination of nozzle size.
6. Type of sprinkler head.
7. Height of riser.
8. Water pressure.
9. Quantity of water per sprinkler head.
10. Riser spacing.

Several lesser important and unknown factors are perhaps also present.

In the study undertaken, the known factors were too numerous to make a complete study on all. It is known that the uniformity of rotation would cause a distorted pattern and give a poor distribution pattern even if all other factors were favorable. For this reason the sprinkler heads were checked for uniformity of rotation periodically, and on any test that rotation was not uniform, the test was thrown out. The speed of rotation was also left out of this study because from other studies it was found that speed of rotation of one to four revolutions per minute will give the best pattern. In this study the speed of rotation was kept between one and two revolutions per minute for all tests.

In all cases the manufacturer's recommendation was accepted as the proper combination of size of range nozzle to size of spreader nozzle.

The following remaining variables were then considered:

1. Wind velocity.
2. Angle of wind with respect to lateral line.
3. Type of sprinkler head.
4. Height of riser.
5. Water pressure at riser.
6. Quantity of water per sprinkler head.
7. Riser spacing in lateral line and between lateral lines.

The limitations and ranges within these variables were limited in the manner described.

The wind velocities used were taken at random as nature provided them. Any wind movement greater than 20 miles per hour was considered unsuitable; therefore, an upper limit of 20 miles per hour was used. Because the work was done during the day the lower wind velocity encountered was 4.8 miles per hour.

Angle of wind with respect to lateral line was divided into three groups as is shown in Figure 6. Group A includes all winds from 0 degrees to 15 degrees from the lateral line, group B includes winds from 16 degrees to 45 degrees from the line, and group C winds from 46 degrees to 90 degrees from the line. The combination of wind velocities to wind angles were taken at random as they were provided for by nature.

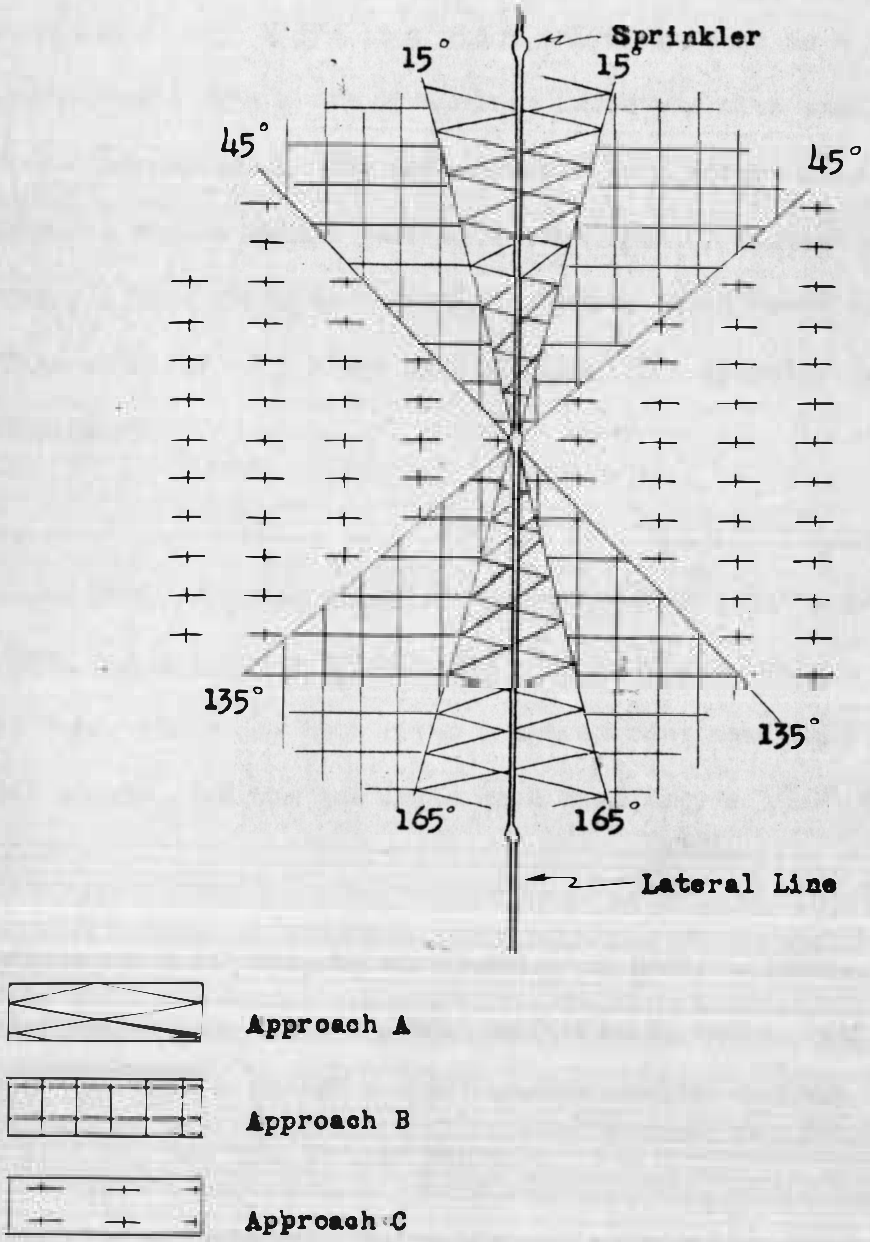

Figure 6. Division of Wind Approach

There are several manufacturers of sprinkler heads and each manufacturer makes several types. In this study all the sprinkler heads were made by one manufacturer. Variations within one make were used. A medium weight head with a 3/4 inch riser inlet was used as a standard head. A heavier head with a one inch riser inlet was also used. This type head has a longer nozzle but not necessarily a larger size opening for the water. A medium weight head with low angle (7 degree) nozzles was also used. A head which is commonly called a "wind head" was checked. This consists of a range nozzle only. The spreader nozzle has a plug inserted.

To vary water quantities, three sets of nozzle combinations were used on the standard 3/4 inch inlet sprinkler head -- 5/32" x 3/32", 13/64" x 5/32", and a 9/32" x 7/32". The wind head used only a 9/32" nozzle. The head with a one inch riser inlet opening used only a 3/16" x 5/32" nozzle, and the low angle head used only a 3/16" x 3/16" nozzle.

Four different riser heights were used -- 6 inch, 12 inch, 24 inch, and 48 inch. The 24 inch riser was most universally used. Only the medium weight head with a 13/64" x 5/32" nozzle combination was used on the 6 inch, 12 inch, and the 48 inch riser.

A complete range of water pressures was used. The range was from 18 pounds per square inch gauge up to 70 pounds per square inch gauge. The major portion of the tests had a pressure between 30 pounds and

50 pounds. Previous experiments have shown that pressures below 30 pounds will give poor distribution patterns even with all the other factors favorable. Because of economic conditions a riser pressure of more than 60 pounds per square inch gauge is seldom used.

A maximum number of combinations of riser spacings and spacing between lateral line moves was used. The riser spacings in the lateral line varied from 10 feet up to a 40 foot spacing. The lateral line moves varied from 30 feet to 60 feet in 10 foot increments. A total of 24 different combinations were used.

All other variables were kept as nearly constant as possible.

METHOD OF PROCEDURE

A standard designed sprinkler system and a total of eight risers were used. From test number one through test 140, the risers were spaced 40 feet apart on the lateral line. Sixteen ounce soil cans were placed five feet apart on a grid system between two risers and as far out as the water was sprinkled. Figure 7 shows the arrangement. The lids of the cans were nailed on 1" x 2" slats forming a holding basin for each can. This insured level cans and even spacing. It also aided in the moving of cans from one location to another. Figure 8 shows the arrangement used. On tests 140 through number 150 only one riser was used and soil cans were placed five feet in every direction so as to catch water from the entire pattern. Water was furnished from an open pit well by a commercial irrigation pump with a gasoline prime mover. By varying the throttle opening any desired pressure could be obtained. A propeller type anemometer as shown in Figure 9 recorded wind velocity and wind direction. The anemometer, mounted on a vane to insure correct position with a small wind directional change, had a constant mounted height of four feet above ground level during all tests. A pressure gauge as shown in Figure 10 was mounted on all risers to record correct pressure readings on each riser.

The duration of each test was one hour, after which time the water was measured volumetrically from each can. Water amounts were recorded in cubic centimeters. An error of one cubic centimeter is equal to an

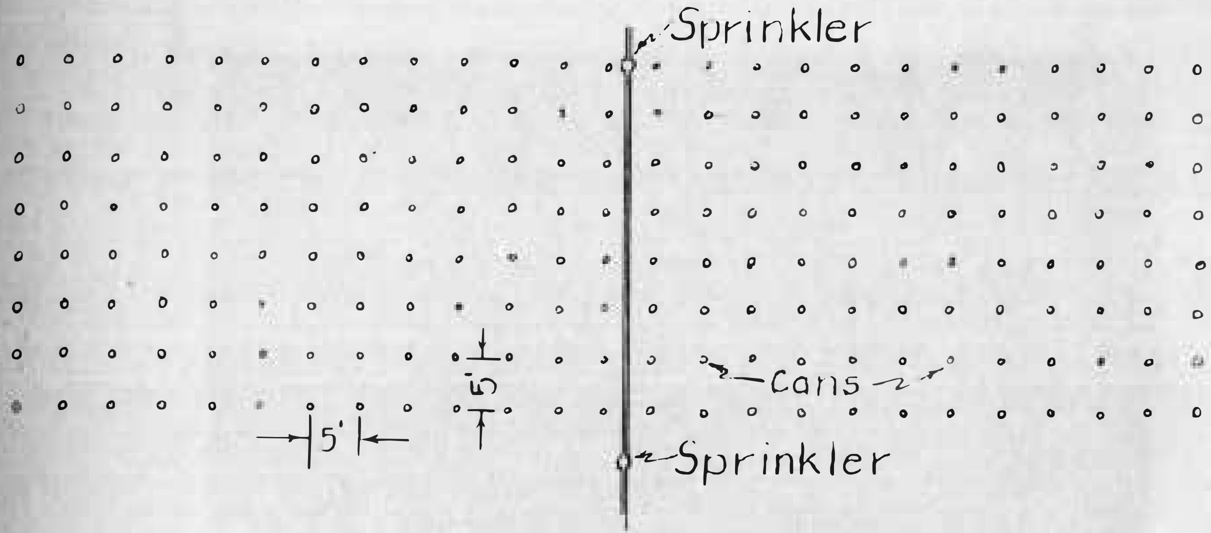

Figure 7. Arrangement of Cans for Tests 1 Through 140

Figure 8. Can Arrangement in Operation

Figure 9. Anemometer in Operation.

Figure 10. Wind Head Mounted on 24 Inch Pressure Gauge Riser.

error of 1/200 inch depth. In analysis the water volume was left in cubic centimeters rather than being changed to inches in depth because a comparison was desired rather than specific amounts. The figures in inches of depth were cumbersome to work with.

A sample data sheet is shown in Appendix A.

In order to obtain patterns for specific spacing the data was superimposed so as to get desired spacing. The method used is shown on a sample data sheet in Appendix B.

To compare sprinkler patterns and to determine how various factors affect the distribution of water a numerical expression was used to serve as an index of uniformity. The uniformity coefficient (K) expressed as a percentage is defined by the equation:

$$K = 100\left(1 - \frac{\Sigma x}{m\, n}\right)$$

In this equation x is the deviation of an individual observation from the mean value m and n is the number of observations. An absolute uniform application would be expressed by the number 100 and a less uniform application by some lower number. Sample calculations and method of recording data may be found in Appendix C.

RESULTS

A summary of all the sprinkler tests giving all the data together with the calculated uniformity coefficient (K) may be found in Table III. In this table, the medium weight sprinkler head with a 3/4" riser inlet opening is designated by the letter A, the low angle nozzle head by B, the wind head by C and head with a 1" riser inlet by D.

For nozzle sizes the following schedule is used:

Size	Symbol
5/32" x 3/32"	1
13/64" x 5/32"	2
9/32" x 7/32"	3
9/32" x plug	4
3/16" x 3/16"	5
3/16" x 5/32"	6

TABLE III

SUMMARY OF SPRINKLER TESTS GIVING PERTINENT DATA TOGETHER WITH THE CALCULATED UNIFORMITY COEFFICIENTS FOR DIFFERENT SPACINGS BETWEEN SPRINKLER HEADS AND SPRINKLER LINES

Test No.	Sprinkler Type*	Nozzle Size**	Pressure, Pounds per Square Inch	Riser Height in Inches	Wind Angle in Degrees	Wind Miles per Hour	Uniformity Coefficients in Per Cent for Various Spacings Between Heads (S_1), and Between Lines (S_2). (S_1) 20 Feet				(S_1) 40 Feet			
							30	40	50	60	30	40	50	60
2	A	2	55	12	10	9.9	93.1	97.4	84.4	64.2	80.4	84.3	75.0	61.0
3	A	2	55	12	0	6.9	91.7	90.6	90.1	70.8	87.0	85.0	84.0	69.7
4	A	2	50	12	0	12.2	86.9	92.0	81.3	59.4	79.6	75.0	69.4	54.2
5	A	2	24	12	10	11.7	88.1	86.7	78.5	58.4	71.2	68.5	62.3	47.2
6	A	2	60	12	5	16.5	90.8	92.0	72.5	52.9	79.2	77.6	65.4	49.4
8	A	2	38	12	40	15.5	79.3	73.0	66.2	51.5	70.4	63.0	58.0	48.4
9	A	2	27	12	35	13.0	88.9	84.9	71.4	55.7	64.7	63.1	53.1	42.0
10	A	2	50	24	30	8.9	88.9	83.4	82.6	69.1	82.5	77.6	76.2	63.6
11	A	2	45	12	10	4.3	97.4	93.0	94.4	78.7	88.6	87.3	87.9	77.2
12	A	2	52	12	15	17.3	90.3	92.1	72.6	54.7	76.2	76.0	65.5	50.7
13	A	2	27	12	10	18.3	90.3	89.1	69.2	54.6	69.9	65.9	49.9	42.4
14	A	2	60	12	30	12.3	90.0	90.7	77.9	58.2	79.3	77.0	69.2	53.5
15	A	2	30	6	15	12.5	89.4	84.1	78.2	62.0	69.6	64.0	61.8	49.0
16	A	2	40	6	20	14.7	91.3	89.1	82.5	64.2	69.5	68.0	64.0	51.8
17	A	2	50	6	30	13.1	89.6	82.4	81.7	67.1	73.7	69.1	69.3	58.1
18	A	2	29	24	20	12.0	90.5	84.9	89.5	71.1	75.6	73.1	71.3	58.1

*A - 3/4" Riser inlet head; B - Low angle head; C - Wind head; D - 1" Riser inlet head.

**1 - 5/32" x 3/32"; 2 - 13/64" x 5/32"; 3 - 9/32" x 7/32"; 4 - 9/32" x plug; 5 - 3/16" x 3/16"; 6 - 3/16" x 5/32".

TABLE III CONTINUED

Test No.	Sprinkler Type	Nozzle Size	Pressure, Pounds per Square Inch	Riser Height in Inches	Wind Angle in Degrees	Wind Miles per Hour	Uniformity Coefficients in Per Cent for Various Spacings Between Heads (S_1), and Between Lines (S_2). (S_1) 20 Feet				(S_1) 40 Feet			
							30	40	50	60	30	40	50	60
19	A	2	40	24	30	5.2	95.4	88.3	92.6	80.4	85.0	81.7	82.5	75.6
21	A	2	25	24	15	7.2	93.3	89.8	89.9	76.0	83.2	81.8	81.1	69.0
22	A	2	40	24	10	7.1	93.8	89.4	93.9	76.9	85.3	82.8	84.1	75.1
23	A	2	60	24	10	7.0	90.9	89.7	93.4	72.3	88.1	86.7	88.2	72.0
24	A	2	30	24	30	6.7	93.7	90.5	90.9	72.7	84.0	83.0	83.1	69.0
25	A	2	40	24	25	7.0	94.6	90.9	94.6	75.1	85.9	83.8	85.9	70.3
27	A	2	53	24	80	9.0	96.3	84.1	84.8	77.2	93.9	82.4	81.1	74.7
29	A	2	45	24	80	13.7	89.4	78.3	77.4	65.7	88.3	76.1	75.3	63.9
33	A	2	45	24	60	6.1	92.7	89.7	87.4	75.0	86.0	83.0	79.0	68.6
37	B	5	38	24	25	6.8	92.1	89.4	83.2	63.6	86.4	83.3	79.1	61.6
39	B	5	47	24	50	2.5	95.6	91.9	93.9	80.6	91.2	90.0	90.2	79.1
40	C	4	37	24	50	2.5	92.4	93.0	82.6	85.0	90.4	89.5	80.8	83.7
41	A	2	63	24	60	4.8	96.4	89.7	90.9	77.4	94.2	88.3	89.2	77.3
42	A	1	58	24	60	4.8	91.5	83.6	69.4	52.8	88.3	81.9	68.8	52.8
45	A	2	29	24	20	7.2	95.4	87.1	85.1	71.4	84.0	80.6	77.3	66.4
46	A	1	25	24	20	7.2	88.1	71.4	55.7	40.0	68.3	58.8	48.6	36.7
47	A	2	50	24	10	8.3	88.6	93.4	82.6	65.2	82.4	83.8	77.6	62.2
48	A	3	40	24	10	8.3	94.9	88.2	94.5	83.4	87.2	84.2	85.9	78.9
49	B	5	51	24	25	8.8	87.3	87.3	84.5	64.3	83.1	81.5	78.6	62.7
50	A	1	46	24	25	8.8	85.9	78.5	56.9	38.4	74.5	68.1	51.4	34.8
51	B	5	40	24	40	9.5	85.7	82.5	77.9	57.4	79.4	75.9	70.8	56.3
53	B	5	40	24	80	6.5	90.3	85.4	87.0	71.2	85.4	81.6	77.7	66.1
54	A	3	30	24	80	6.5	96.4	84.2	87.3	96.4	81.3	75.7	78.1	81.3
55	A	2	40	24	45	7.9	96.8	82.8	84.2	96.8	89.2	78.7	82.6	89.2

TABLE III CONTINUED

Test No.	Sprinkler Type	Nozzle Size	Pressure, Pounds per Square Inch	Riser Height in Inches	Wind Angle in Degrees	Wind Miles per Hour	Uniformity Coefficients in Per Cent for Various Spacings Between Heads (S_1), and Between Lines (S_2). (S_1) 20 Feet				(S_1) 40 Feet			
							30	40	50	60	30	40	50	60
57	A	2	50	24	65	7.3	94.5	87.8	89.0	80.8	89.9	84.7	83.2	75.3
59	A	2	40	24	60	10.2	85.8	82.4	82.4	73.0		78.0	77.7	70.6
61	A	2	30	24	75	10.1	93.1	81.4	75.3	71.0	86.9	77.9	74.9	66.7
64	C	4	45	24	70	9.7	94.2	83.6	82.9	78.1	74.0	70.0	68.2	64.4
65	A	2	48	24	30	6.4	90.9	85.5	95.7	80.0	85.7	82.2	84.6	73.7
66	C	4	42	24	20	6.4	93.8	81.1	86.8	91.5	87.7	79.9	83.5	84.6
67	A	2	40	24	20	6.0	89.1	89.3	96.9	80.4	81.7	85.8	88.5	78.5
68	A	3	30	24	20	6.0	95.6	87.6	92.0	91.5	92.3	86.4	88.4	88.1
69	B	5	46	24	0	9.7	79.4	88.5	71.8	51.6	73.6	75.4	64.6	50.1
70	C	4	42	24	0	9.7	85.4	78.4	91.9	77.1	78.6	75.0	80.0	69.6
71	B	5	58	24	0	10.5	79.6	90.8	69.0	48.6	75.1	75.0	61.6	46.0
72	C	4	48	24	0	10.5	84.7	81.9	93.4	73.9	80.3	77.9	81.4	68.3
73	B	5	25	24	0	11.8	83.8	87.6	66.3		71.2	60.3	50.0	
74	C	4	18	24	0	11.8	84.4	80.8	90.6	69.9	66.1	70.1	65.6	52.8
75	B	5	50	24	10	13.6	87.2	86.6	62.5	44.2	68.5	66.4	52.7	37.9
76	C	4	43	24	10	13.6	87.6	84.0	89.0	73.5	79.1	74.0	77.1	64.1
78	C	4	32	24	30	13.6	87.9	85.0	88.3	71.2	76.1	73.3	73.2	61.4
79	C	4	29	24	10	17.4	88.6	88.6	70.7	54.7	68.9	67.3	56.7	40.3
80	A	1	25	24	10	17.4	76.5	64.1	31.1		69.5	47.5	17.4	
81	C	4	40	24	25	18.6	86.0	88.2	74.9	54.3	78.5	78.6	68.7	51.2
82	A	1	35	24	25	18.6	90.8	78.6	57.3	37.6	73.6	66.8	49.7	31.6
83	C	4	56	24	25	16.7	86.3	93.6	72.2	50.5	81.8	82.8	69.3	50.5
84	A	1	50	24	25	16.7	88.5	83.9	59.5	40.0	76.3	72.5	54.6	37.1
85	C	4	25	24	25	16.7	87.6	81.6	64.4	46.8	58.2	55.0	47.5	40.2
86	A	1	23	24	25	16.7	80.9	61.1	32.9		49.0	37.2	15.1	

TABLE III CONTINUED

Test No.	Sprinkler Type	Nozzle Size	Pressure, Pounds per Square Inch	Riser Height in Inches	Wind Angle in Degrees	Wind Miles per Hour	Uniformity Coefficients in Per Cent for Various Spacings Between Heads (S_1), and Between Lines (S_2). (S_1) 20 Feet				(S_1) 40 Feet			
							30	40	50	60	30	40	50	60
87	B	5	32	24	80	9.3	85.6	93.3	76.5	57.6	80.9	73.7	68.6	53.1
88	A	3	25	24	80	9.3	92.8	89.1	84.4	79.2	80.1	74.0	70.0	65.8
89	B	5	32	24	30	17.8	84.9	84.1	75.7	59.3	82.6	79.3	70.8	55.1
90	A	3	24	24	30	17.8	93.9	82.2	84.9	78.7	83.5	76.0	75.0	69.7
91	B	5	52	24	30	10.3	83.4	90.8	76.0	55.3	78.4	80.8	70.7	53.2
92	A	3	42	24	40	10.3	94.7	87.0	88.3	84.7	82.1	78.8	78.6	75.8
94	A	2	42	48	40	9.6	87.2	84.6	93.1	74.1	82.3	79.7	84.4	70.0
96	A	2	28	48	25	9.2	94.4	81.5	91.2	85.6	86.1	77.8	83.7	79.2
100	A	2	25	24	25	4.8	96.0	88.3	91.0	82.1	88.0	84.4	85.6	79.6
101	D	6	40	24	50	8.0	94.7	90.1	85.3	87.7	90.3	75.6	81.8	82.4
102	A	3	31	24	50	8.0	91.7	82.6	83.9	90.1	88.2	81.0	80.9	76.8
103	D	6	33	24	25	7.5	95.2	77.5	80.6	92.2	83.4	74.4	75.9	81.4
104	A	3	25	24	25	7.5	93.9	83.9	85.8	90.4	85.0	80.3	81.1	80.0
106	A	1	45	24	40	9.3	89.2	85.8	74.9	54.7	82.5	79.1	69.8	53.7
108	A	1	21	24	30	9.0	89.7	72.7	59.0	41.5	70.1	61.4	51.2	36.9
110	D	6	35	24	25	8.8	94.0	81.3	80.9	80.9	88.5	79.2	76.5	76.5
111	A	2	47	48	25	17.5	94.7	92.7	80.6	62.3	87.1	86.0	78.8	61.4
112	D	6	42	24	25	17.5	90.5	85.9	81.6	65.5	76.0	72.1	69.4	55.6
115	A	2	33	48	30	16.0	87.9	86.5	77.0	58.8	82.3	81.2	72.7	56.7
116	D	6	28	24	30	16.0	89.6	85.2	86.8	71.5	79.5	74.5	73.5	60.7
117	C	4	51	24	30	15.3	92.3	88.4	87.0	74.2	86.6	82.5	81.8	70.3
118	A	1	52	24	30	15.3	87.7	82.9	68.4	52.1	76.3	72.8	62.9	48.7
119	C	4	47	24	30	15.3	88.0	81.6	87.7	70.6	79.1	75.1	79.6	70.6
120	A	1	42	24	30	15.3	88.3	82.7	68.7	48.0	76.7	71.7	63.9	48.0
121	D	6	30	24	70	9.0	95.5	84.2	83.2	70.2	76.2	72.2	71.1	70.2
122	A	1	36	24	70	9.0	89.8	80.4	71.3	55.7	82.4	77.3	68.4	55.7

TABLE III CONTINUED

Test No.	Sprinkler Type	Nozzle Size	Pressure, Pounds per Square Inch	Riser Height in Inches	Wind Angle in Degrees	Wind Miles per Hour	Uniformity Coefficients in Per Cent for Various Spacings Between Heads (S_1), and Between Lines (S_2). (S_1) 20 Feet: 30	40	50	60	(S_1) 40 Feet: 30	40	50	60
123	D	6	49	24	70	11.4	91.7	80.7	83.9	67.8	80.8	75.4	74.5	67.8
124	A	1	46	24	70	11.4	90.6	78.9	75.2	62.0	85.5	74.6	70.1	62.0
125	C	4	32	24	60	11.7	91.9	78.4	80.5	71.1	84.6	75.7	76.1	71.1
126	A	1	31	24	60	11.7	84.1	73.2	62.2	50.4	77.6	67.9	60.6	50.4
127	C	4	58	24	70	13.1	93.2	89.0	84.8	68.6	86.2	83.0	79.0	68.6
128	A	2	56	24	70	13.1	94.9	89.8	85.9	61.7	89.7	85.1	81.0	61.7
129	C	4	43	24	60	7.9	91.1	83.2	81.8	65.8	81.1	78.2	74.7	65.8
130	A	2	42	24	60	7.9	93.5	85.7	83.1	68.1	86.6	80.6	75.8	68.1
131	A	2	49	24	75	6.1	92.4	88.7	89.5	74.0	86.9	83.3	82.5	74.0
132	A	2	46	48	80	6.1	94.5	91.8	91.4	77.5	85.1	83.8	81.9	77.5
135	A	2	39	24	45	10.7	95.2	92.2	90.3	72.7	83.5	81.4	79.8	72.7
136	D	6	34	24	45	10.7	94.7	86.9	93.4	80.2	86.2	82.7	84.5	80.2
137	A	3	53	24	15	8.2	93.6	89.0	92.3	79.5	84.9	81.7	83.4	79.5
138	A	2	51	48	30	8.2	92.0	90.1	93.3	77.5	90.3	88.2	88.9	77.5
139	A	2	40	24	40	1.5	95.2	96.1	87.6	89.1	94.6	95.6	87.3	89.1
140	D	6	33	24	40	1.5	94.9	95.6	83.4	75.9	93.5	93.5	82.0	75.9
141	A	2	49	24	15	7.2	96.5	91.8	92.0	81.8	91.0	88.6	89.1	81.8
142	A	2	42	24	45	10.2	95.2	89.9	86.3	75.6	87.8	85.4	82.3	75.6
143	A	2	42	24	45	10.2	95.4	88.4	85.5	75.4	90.3	86.7	82.9	75.4
144	A	2	48	48	45	6.4	95.4	95.5	91.8	80.8	90.4	82.3	87.4	80.8
145	A	2	58	48	10	6.6	92.9	91.5	89.9	72.0	90.0	88.7	87.5	72.0
147	A	2	51	24	10	12.6	89.7	89.4	82.1	60.7	81.8	80.8	76.1	60.7
148	A	2	40	24	10	11.7	90.5	88.5	85.8	71.4	76.9	74.0	73.7	62.4
149	A	2	35	24	20	11.1	94.2	94.2	84.7	76.4	77.1	77.1	74.7	70.5
150	A	2	40	24	20	15.2	92.7	92.7	96.2	71.9	83.7	83.7	86.2	63.6

TABLE III

SUMMARY OF SPRINKLER TESTS GIVING PERTINENT DATA TOGETHER WITH THE CALCULATED UNIFORMITY COEFFICIENTS FOR DIFFERENT SPACINGS BETWEEN SPRINKLER HEADS AND SPRINKLER LINES

Test No.	Sprinkler Type*	Nozzle Size**	Pressure, Pounds per Square Inch	Riser Height in Inches	Wind Angle in Degrees	Wind Miles per Hour	Uniformity Coefficients in Per Cent for Various Spacings Between Heads (S_1), and Between Lines (S_2). (S_1) 15 Feet				(S_1) 25 Feet			
							30	40	50	60	30	40	50	60
141	A	2	49	24	15	7.2	94.2	91.3	87.4	74.6	96.4	91.6	91.9	85.4
142	A	2	42	24	45	10.2	95.8	90.1	88.2	79.4	96.3	91.4	86.7	81.0
143	A	2	42	24	45	10.2	95.9	87.3	85.0	77.5	96.8	88.2	85.9	77.8
144	A	2	48	48	45	6.4	94.3	90.1	90.9	83.9	94.4	90.9	90.7	80.1
145	A	2	58	48	10	6.6	92.8	91.4	89.2	72.4	93.5	92.4	89.7	72.2
147	A	2	51	24	10	12.6	89.5	90.0	81.8	64.0	85.5	87.3	81.1	63.2
148	A	2	40	24	10	11.7	90.3	85.4	83.1	70.6	88.1	84.8	82.8	70.1
149	A	2	35	24	20	11.1	89.5	89.5	86.8	71.7	93.0	90.9	88.8	75.4
150	A	2	40	24	20	15.2	90.2	85.9	87.4	75.7	92.5	86.2	89.9	78.7

*A - 3/4" Riser inlet head; B - Low angle head; C - Wind head; D - 1" Riser inlet head.

**1 - 5/32" x 3/32"; 2 - 13/64" x 5/32"; 3 - 9/32" x 7/32"; 4 - 9/32" x plug; 5 - 3/16" x 3/16"; 6 - 3/16" x 5/32".

ANALYSIS OF RESULTS

Effect of Riser Height

From previous work it is known that on wind velocities under four miles per hour, riser height has little or no effect on the distribution pattern. In this analysis wind velocities of 4.8 miles per hour or greater were used. Conditions were as nearly identical as possible with the exception of riser height. Table IV shows a comparison between a 6 inch riser and a 24 inch riser. This is a paired analysis which shows that there is a highly significant difference between the two heights. A 24 inch riser will give about a 10 per cent better pattern than a 6 inch riser -- all other conditions being equal.

Table V shows a like comparison between 12 inch risers and 24 inch risers. A significant difference was not present. The analysis does indicate that there is a definite trend toward the 24 inch riser being more satisfactory than a 12 inch riser. In this analysis there is only a 12 inch difference in the heights of the compared risers, whereas in the comparison in Table IV there was a difference of 18 inches and in the table to follow a difference of 24 inches. This may be why there was not a significant difference present in this comparison.

A comparison between a 24 inch riser and a 48 inch riser is shown in Table VI. A significant difference of 3.7 per cent was found. The 48 inch riser makes it possible to obtain a better pattern.

TABLE IV

SUMMARY OF STATISTICS FOR COMPARISON OF 6 INCH RISER AND 24 INCH RISER

Sprinkler Type	Nozzle Size	Pressure	Wind Velocity	Spacing	K 6 Inch	K 24 Inch
A	2	40	14.7	40 x 30	69.5	88.3
A	2	30	12.5	40 x 30	69.6	75.6
A	2	50	13.1	40 x 30	73.7	89.9
A	2	40	14.7	40 x 40	68.0	76.1
A	2	30	12.5	40 x 40	64.0	73.1
A	2	50	13.1	40 x 40	69.1	85.1
A	2	40	14.7	40 x 50	64.0	75.3
A	2	30	12.5	40 x 50	61.8	71.3
A	2	50	13.1	40 x 50	69.3	81.0
A	2	40	14.7	40 x 60	51.8	63.9
A	2	30	12.5	40 x 60	49.0	58.1
A	2	50	13.1	40 x 60	58.1	61.7

Height	Number of Tests	D_f	Mean Value of K	Sum of Squares
6	12	11	64.0	639
24	12	11	74.9	1119
	Sum	22	Difference 10.9	Sum 1758

$s_{\bar{x}} = 3.65$ $t = 2.99$

$t = 10.9/3.65$ P less than 2%

TABLE V

SUMMARY OF STATISTICS FOR COMPARISON OF 12 INCH RISER AND 24 INCH RISER

Sprinkler Type	Nozzle Size	Pressure	Wind Velocity	Spacing	K 6 Inch	K 24 Inch
A	2	45	4.3	40 x 30	88.6	94.2
A	2	55	6.9	40 x 30	87.0	88.1
A	2	55	9.9	40 x 30	80.4	82.5
A	2	50	12.2	40 x 30	79.6	81.8
A	2	24	11.7	40 x 30	71.2	75.6
A	2	60	12.3	40 x 30	79.3	89.7
A	2	45	4.3	40 x 40	87.3	88.3
A	2	55	6.9	40 x 40	85.0	86.2
A	2	55	9.9	40 x 40	84.3	77.6
A	2	50	12.2	40 x 40	75.0	80.8
A	2	24	11.7	40 x 40	68.5	73.1
A	2	60	12.3	40 x 40	77.0	85.1
A	2	45	4.3	40 x 50	87.9	89.2
A	2	55	6.9	40 x 50	84.0	88.2
A	2	55	9.9	40 x 50	75.0	76.2
A	2	50	12.2	40 x 50	69.4	76.1
A	2	24	11.7	40 x 50	62.3	71.3
A	2	60	12.3	40 x 50	69.2	81.0
A	2	45	4.3	40 x 60	77.2	82.3
A	2	55	6.9	40 x 60	69.7	72.0
A	2	55	9.9	40 x 60	61.0	63.6
A	2	50	12.2	40 x 60	54.2	60.7
A	2	24	11.7	40 x 60	47.2	58.1
A	2	60	12.3	40 x 60	53.5	61.7

Height	Number of Tests	D_f		Mean Value of K		Sum of Squares
12	24	23		73.9		3134
24	24	23		78.5		2287
	Sum	46	Difference	4.6	Sum	5421

$s_{\bar{x}} = 3.13$ $\qquad$ $t = 1.47$

$t = 4.6/3.13$ $\qquad$ P greater than 16%

TABLE VI

SUMMARY OF STATISTICS FOR COMPARISON OF 24 INCH RISER AND 48 INCH RISER

Sprinkler Type	Nozzle Size	Pressure	Wind Velocity	Spacing	K 24	K 48
A	2	45	6.1	40 x 30	86.0	85.1
A	2	48	6.4	40 x 30	85.7	90.4
A	2	60	7.0	40 x 30	88.1	90.0
A	2	42	7.9	40 x 30	86.6	90.3
A	2	30	10.1	40 x 30	86.9	86.1
A	2	40	10.2	40 x 30	80.2	82.3
A	2	45	6.1	40 x 40	83.0	83.8
A	2	48	6.4	40 x 40	82.2	82.3
A	2	60	7.0	40 x 40	86.2	88.7
A	2	42	7.9	40 x 40	80.6	88.2
A	2	30	10.1	40 x 40	77.9	77.8
A	2	40	10.2	40 x 40	78.0	79.7
A	2	45	6.1	40 x 50	79.0	81.9
A	2	48	6.4	40 x 50	84.5	87.4
A	2	60	7.0	40 x 50	88.2	87.5
A	2	42	7.9	40 x 50	75.8	88.9
A	2	30	10.1	40 x 50	74.9	83.7
A	2	40	10.2	40 x 50	77.7	84.4
A	2	45	6.1	40 x 60	68.6	77.5
A	2	48	6.4	40 x 60	73.7	80.8
A	2	60	7.0	40 x 60	72.0	72.0
A	2	42	7.9	40 x 60	68.1	77.5
A	2	30	10.1	40 x 60	66.7	69.6
A	2	40	10.2	40 x 60	70.6	70.1

Height	Number of Tests	D_f		Mean Value of K	Sum of Squares
24	24	23		79.2	1049
48	24	23		82.9	709
	Sum	46	Difference	3.7	Sum 1758

$s_{\bar{x}} = 1.78$ $\qquad$ $t = 2.08$

$t = 3.7/1.78$ $\qquad$ P less than 5%

Riser heights of greater than 48 inches would perhaps be still better but because of difficulty in handling taller risers under actual irrigating conditions they were omitted from this study.

In all subsequent analyses a riser height of 24 inches will be used.

Angle Of Wind With Respect To Lateral Line

The angle of the wind with respect to lateral line has been divided into three groups as is shown in Figure 6. Summary of analysis is shown in Tables VII, VIII, and IX. Horizontal columns have as nearly as possible, identical conditions with the exception of angle of wind approach. In no case was a significant difference found in pattern coefficient due to angle of wind approach. The trend indicates that a wind angle between 15 degrees and 45 degrees will give a better pattern than the other angles. Little difference was found between a wind parallel and a wind perpendicular to the lateral line.

In all the remaining analyses the angle of wind approach will be disregarded.

Effect Of Wind Velocity And Riser Spacing

This analysis is confined to the medium weight sprinkler head with a 3/4" riser inlet on a 24 inch riser. In all cases 13/64" x 5/32" nozzles were used.

TABLE VII

SUMMARY OF STATISTICS FOR COMPARISON OF WIND ANGLES IN GROUP A AND B

Sprinkler Type	Nozzle Size	Pressure	Wind Velocity	Spacing	K Angle A	K Angle B
A	2	55	12.3	40 x 30	79.6	79.3
A	2	50	8.3	40 x 30	82.4	82.5
B	5	58	10.3	40 x 30	75.1	78.4
B	5	46	9.7	40 x 30	73.6	79.4
A	2	40	7.1	40 x 30	85.3	85.9
A	2	55	12.3	40 x 40	75.0	77.0
A	2	50	8.3	40 x 40	83.8	77.6
B	5	58	10.3	40 x 40	75.0	80.8
B	5	46	9.7	40 x 40	75.4	75.9
A	2	40	7.1	40 x 40	82.8	83.8
A	2	55	12.3	40 x 50	69.4	69.2
A	2	50	8.3	40 x 50	77.6	76.2
B	5	58	10.3	40 x 50	61.6	70.0
B	5	46	9.7	40 x 50	64.6	70.8
A	2	40	7.1	40 x 50	84.1	83.5
A	2	55	12.3	40 x 60	54.2	53.5
A	2	50	8.3	40 x 60	62.2	63.6
B	5	58	10.3	40 x 60	46.0	53.2
B	5	46	9.7	40 x 60	50.1	56.3
A	2	40	7.1	40 x 60	75.1	70.3

Angle	Number of Tests	D_f	Mean Value of K	Sum of Squares
A	20	19	71.6	2601
B	20	19	73.3	1862
		Sum 38	Difference 1.7	Sum 4463

$s_{\bar{x}}$ = 3.11 $\qquad$ t = 0.55

t = 1.7/3.11 $\qquad$ P greater than 50%

TABLE VIII

SUMMARY OF STATISTICS FOR COMPARISON OF WIND ANGLES IN GROUP A AND C

Sprinkler Type	Nozzle Size	Pressure	Wind Velocity	Spacing	K Angle A	K Angle C
A	2	50	7.3	40 x 50	89.0	83.2
A	2	42	8.3	40 x 50	77.6	75.8
A	3	40	8.3	40 x 50	85.9	80.9
C	4	42	9.7	40 x 50	80.0	78.2
A	2	56	12.6	40 x 50	76.1	81.0
A	2	50	7.3	40 x 60	81.8	85.3
A	2	42	8.3	40 x 60	62.2	68.1
A	3	40	8.3	40 x 60	78.9	76.8
C	4	42	9.7	40 x 60	68.6	64.4
A	2	56	12.6	40 x 60	60.7	61.7

Angle	Number of Tests	Df		Mean Value of K	Sum of Squares
A	10	9		76.1	914
C	10	9		75.6	501
		Sum 18	Difference	0.5	Sum 1415

$s_{\bar{x}} = 3.70$ $\qquad$ $t = 0.14$

$t = 0.5/3.70$ $\qquad$ P greater than 50%

TABLE IX

SUMMARY OF STATISTICS FOR COMPARISON OF WIND ANGLES OF GROUP B AND C

Sprinkler Type	Nozzle Size	Pressure	Wind Velocity	Spacing	K Angle B	K Angle C
A	2	48	6.4	40 x 30	85.7	86.9
B	5	38	6.8	40 x 30	86.4	85.4
B	5	40	9.5	40 x 30	79.4	80.9
A	2	24	8.9	40 x 30	82.5	86.6
A	2	29	12.0	40 x 30	75.6	86.9
A	2	48	6.4	40 x 40	82.2	83.3
B	5	38	6.8	40 x 40	83.3	81.6
A	2	24	8.9	40 x 40	77.6	80.6
B	5	40	9.5	40 x 40	75.9	73.7
A	2	29	12.0	40 x 40	73.1	77.9
A	2	48	6.4	40 x 50	84.5	82.5
B	5	38	6.8	40 x 50	79.1	77.7
A	2	24	8.9	40 x 50	76.2	75.8
B	5	40	9.5	40 x 50	70.8	68.6
A	2	29	12.0	40 x 50	71.3	74.9
A	2	48	6.4	40 x 60	73.7	74.0
B	5	38	6.8	40 x 60	61.6	66.1
A	2	24	8.9	40 x 60	63.6	68.1
B	5	40	9.5	40 x 60	56.3	53.1
A	2	29	12.0	40 x 60	58.1	66.7

Angle	Number of Tests	D_f		Mean Value of K		Sum of Squares
B	20	19		74.8		1537
C	20	19		76.6		1446
		Sum 38	Difference	1.8	Sum	2983

$s_{\bar{x}} = 2.80$ $t = 0.64$

$t = 1.8/2.80$ P greater than 50%

In order to make this analysis pressures were divided up into four increments:

25 psig to 33 psig with an average of 28.7 psig
39 psig to 42 psig with an average of 40.0 psig
45 psig to 50 psig with an average of 47.8 psig
53 psig to 63 psig with an average of 56.0 psig

For each of these increments the equation for the line was calculated for each of the following eight riser and lateral spacings:

40 feet x 30 feet	20 feet x 30 feet
40 feet x 40 feet	20 feet x 40 feet
40 feet x 50 feet	20 feet x 50 feet
40 feet x 60 feet	20 feet x 60 feet

Summarization of the equations is shown in Table X. Sample calculations may be found in Appendix D. The equations are plotted in Figures 11 through 18. A higher correlation factor may have been obtained in some cases if more tests would have been available.

The graphs show that there is a definite breaking point between a 50 foot lateral move and a 60 foot lateral move. This indicates that under the conditions of the tests a maximum lateral move is 50 feet.

Effect Of Pressure

Using the calculated equation in Table X a comparison of pressures is possible. Figure 19 is a plotting of the lines for a 40' x 50' spacing with a medium weight sprinkler head with a 3/4" riser inlet on a 24" riser. In all cases 13/64" x 5/32" nozzles were used. It shows that there is little difference between 56 pounds pressure and 48 pounds pressure. There is little difference in 40 pounds or 28 pounds pressure.

TABLE X

EQUATIONS FOR DISTRIBUTION LINES USING VARIOUS SPACINGS AND PRESSURES*

K B AX

K Uniformity Coefficient X Wind Velocity in Miles per Hour

Spacing in Feet	27.8 pounds per Square Inch		40.0 Pounds per Square Inch		47.8 Pounds per Square Inch		56.0 Pounds per Square Inch	
	K	r**	K	r**	K	r**	K	r**
40 x 30	94.1 - 1.5 X	0.48	97.1 - 1.6 X	0.82	96.1 - 0.8 X	0.61	96.1 - 0.7 X	0.59
40 x 40	94.0 - 1.7 X	0.40	97.9 - 2.0 X	0.94	93.0 - 0.9 X	0.40	96.1 - 1.1 X	0.48
40 x 50	93.0 - 1.9 X	0.75	98.6 - 2.3 X	0.71	95.1 - 1.4 X	0.51	94.2 - 1.2 X	0.86
40 x 60	88.2 - 2.3 X	0.70	92.9 - 2.6 X	0.92	88.9 - 1.6 X	0.81	87.3 - 1.9 X	0.56
20 x 30	98.7 - 0.6 X	0.86	98.7 - 0.7 X	0.65	93.7 - 0.2 X	0.60	98.7 - 0.5 X	0.74
20 x 40	95.9 - 0.6 X	0.84	95.0 - 0.9 X	0.96	93.0 - 0.8 X	0.58	98.0 - 0.8 X	0.71
20 x 50	93.7 - 1.7 X	0.63	94.9 - 1.1 X	0.61	97.4 - 1.2 X	0.77	97.0 - 0.9 X	0.74
20 x 60	89.0 - 2.3 X	0.69	93.0 - 2.1 X	0.91	91.0 - 1.7 X	0.58	92.0 - 1.7 X	0.94

*Medium Weight Head on 24 Inch Riser Using 13/64" x 5/32" Nozzle.

**Correlation Factors Are All Negative.

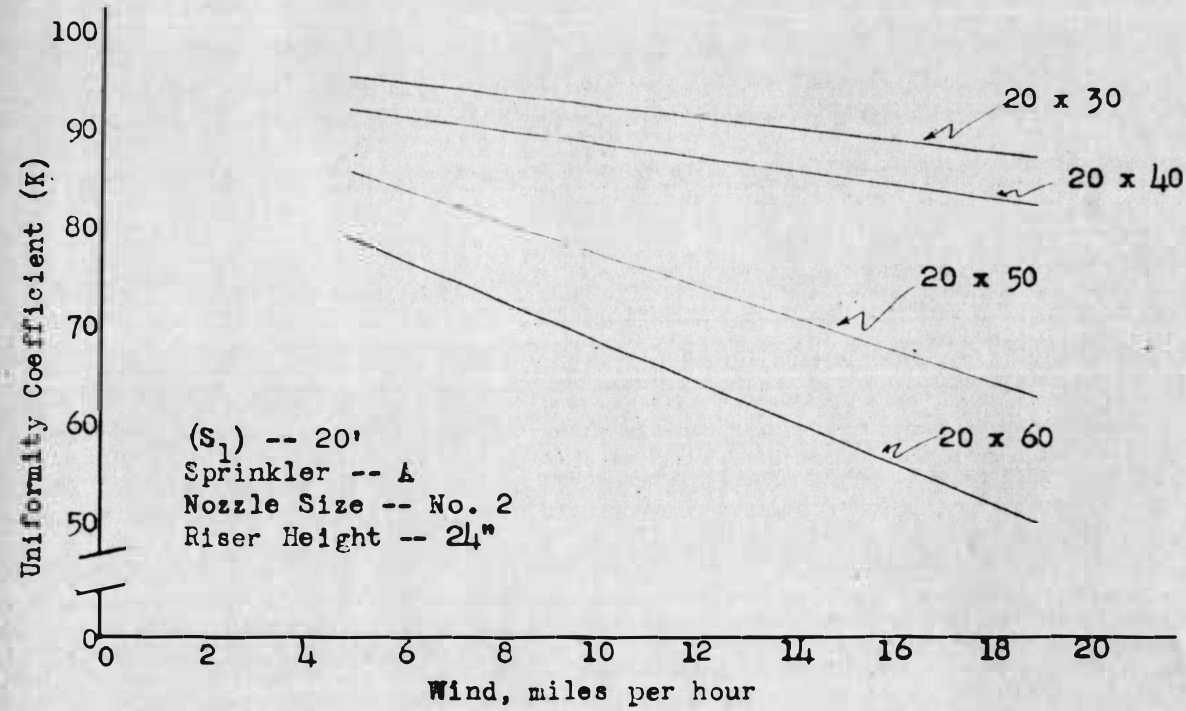

Figure 11. Uniformity for 28 Pound Pressure.

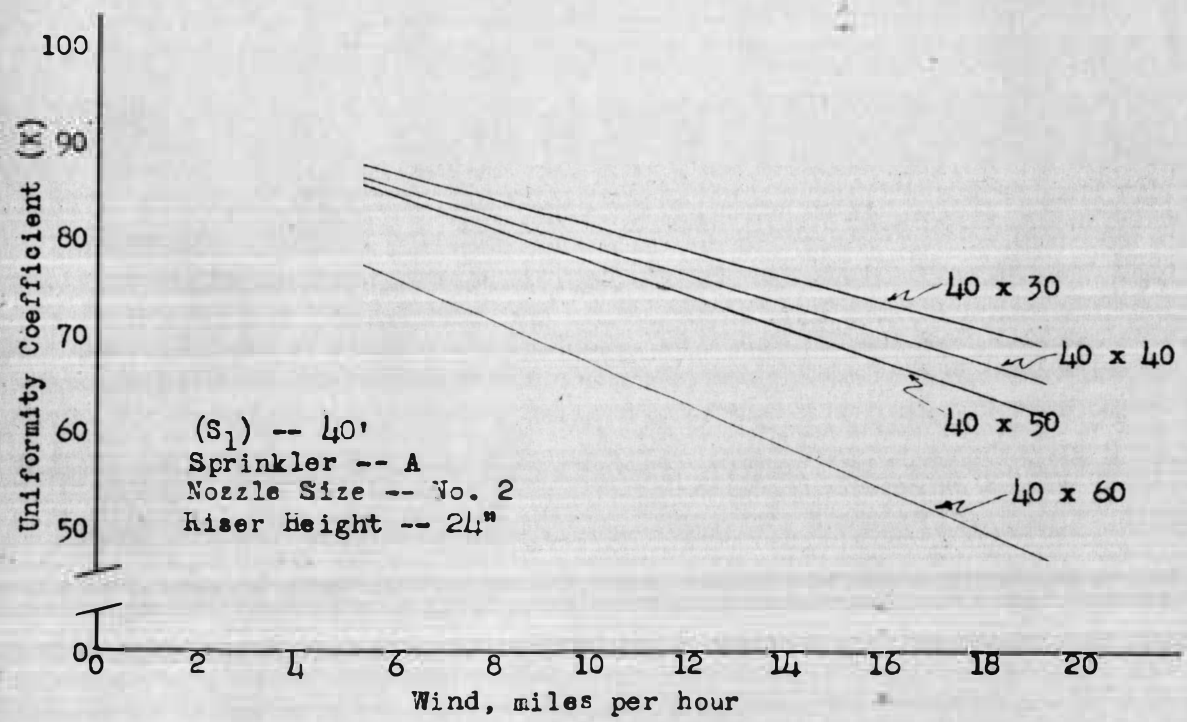

Figure 12. Uniformity for 28 Pound Pressure.

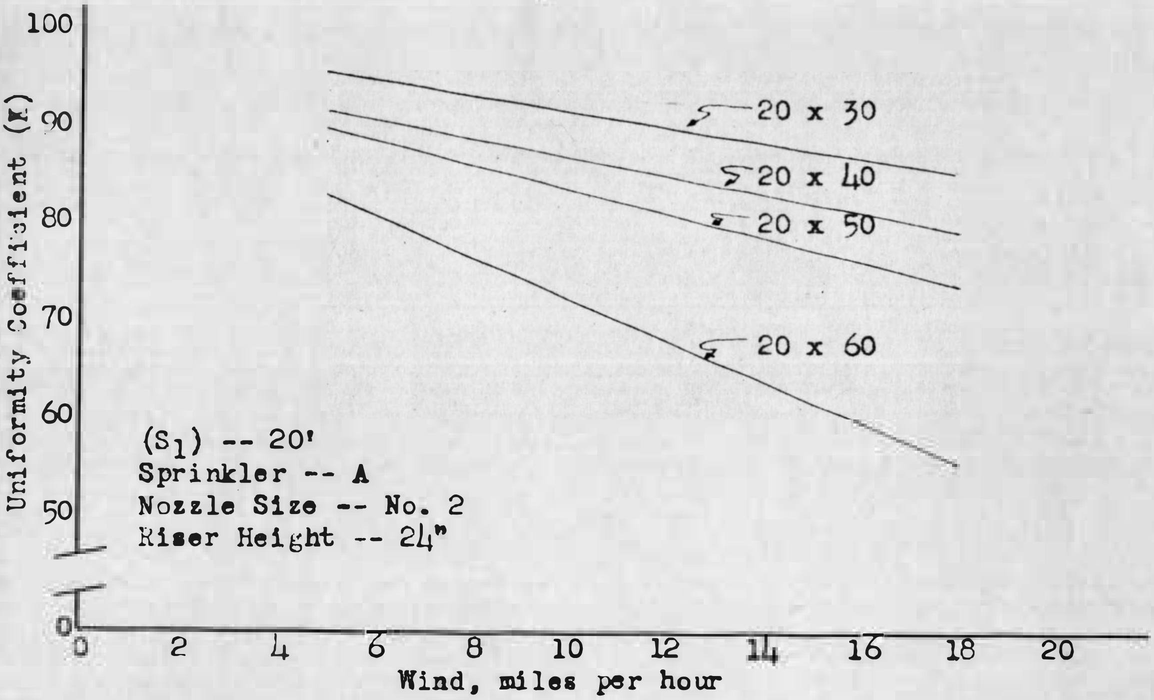

Figure 13. Uniformity for 40 Pound Pressure.

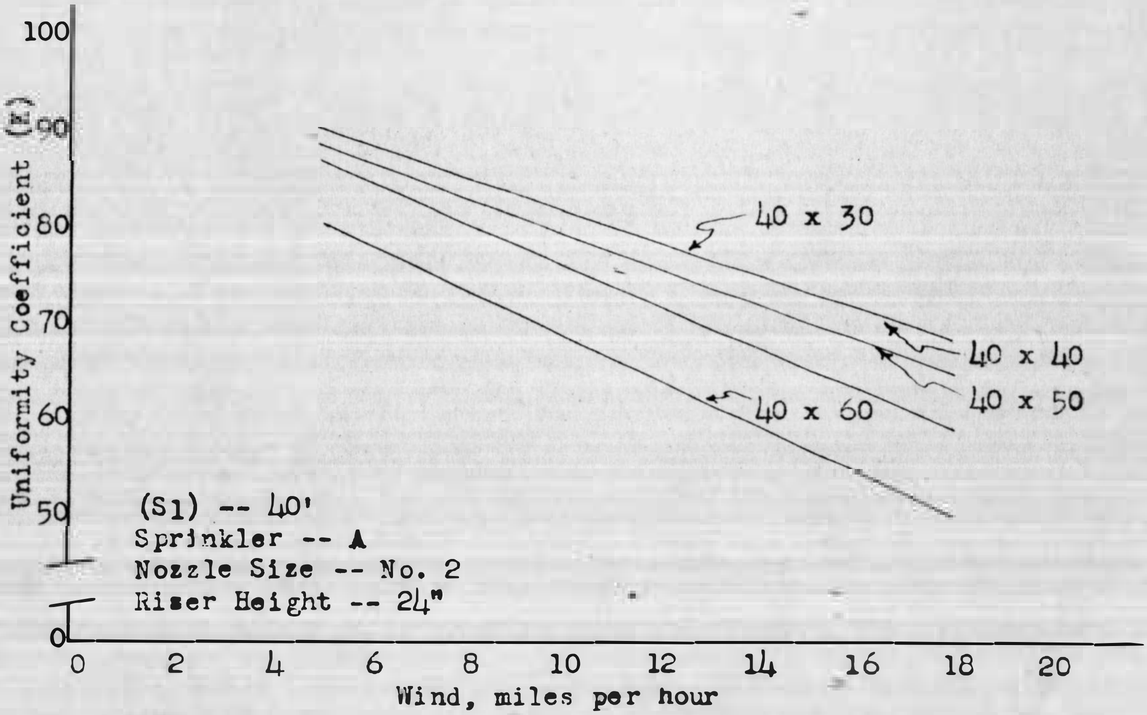

Figure 14. Uniformity for 40 Pound Pressure.

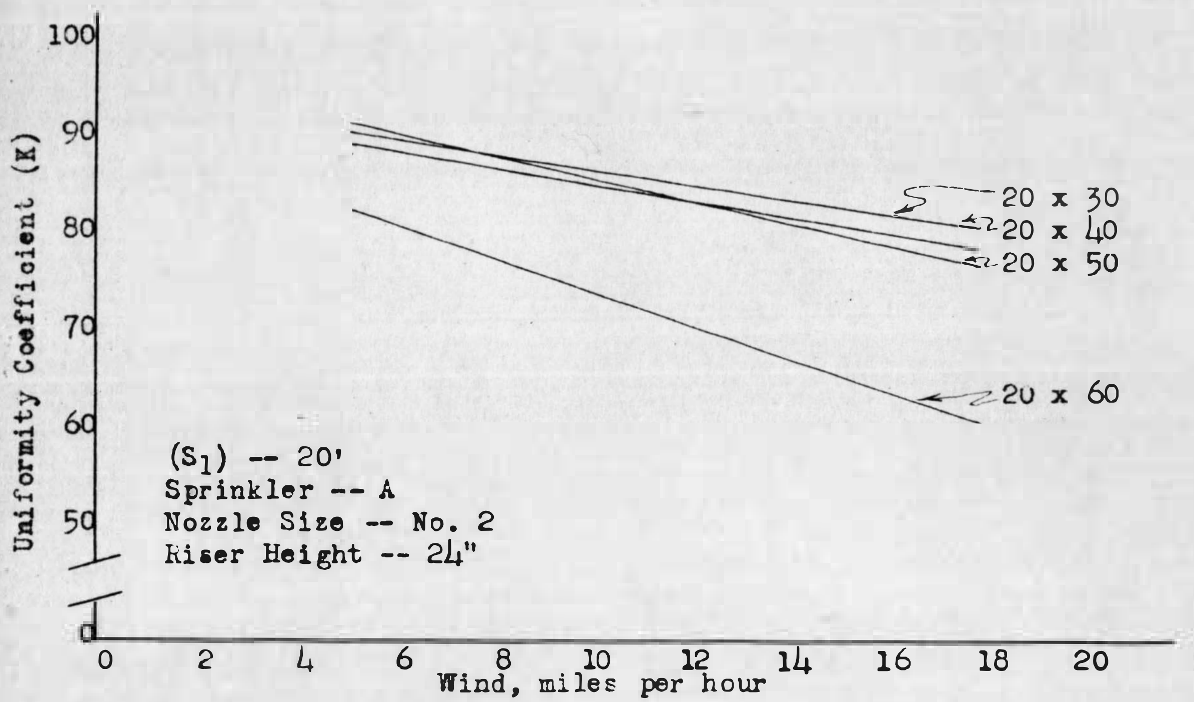

Figure 15. Uniformity for 48 Pound Pressure.

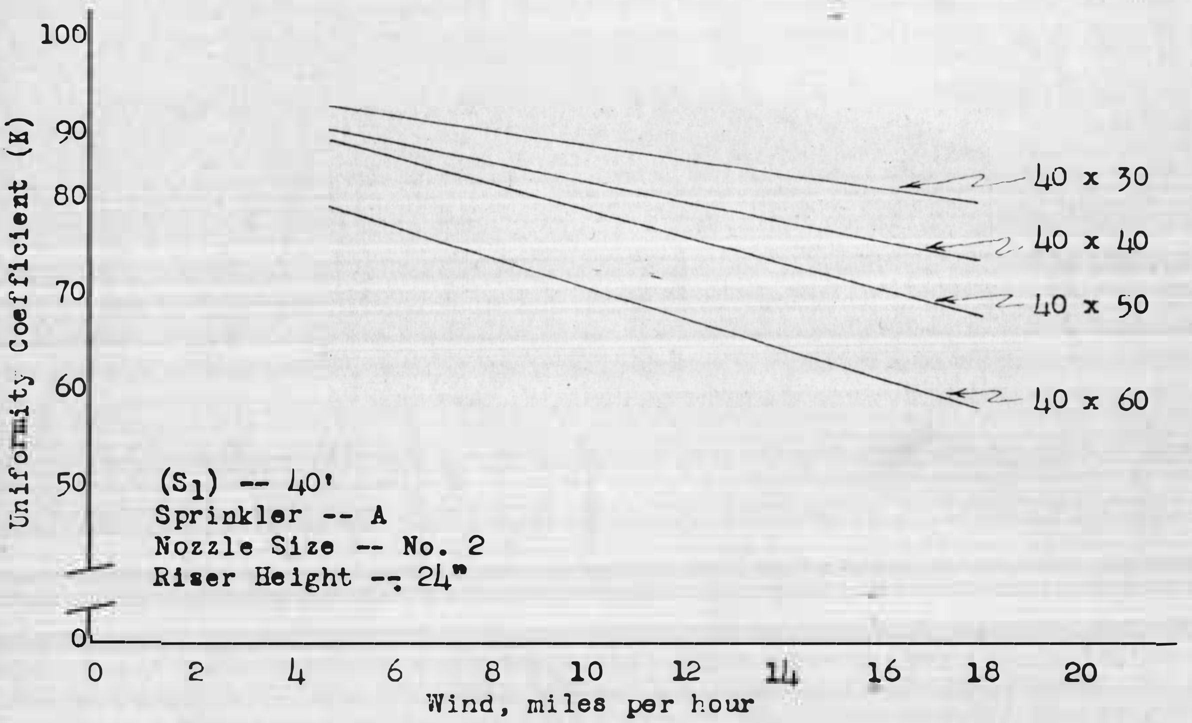

Figure 16. Uniformity for 48 Pound Pressure.

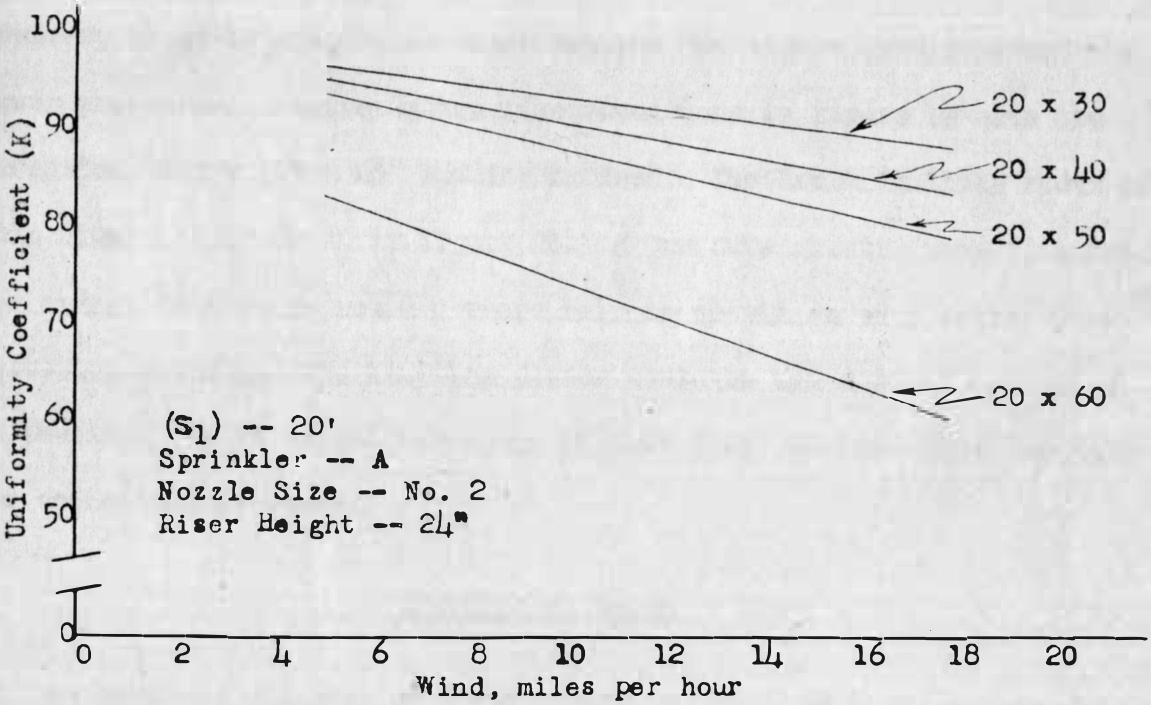

Figure 17. Uniformity for 56 Pound Pressure

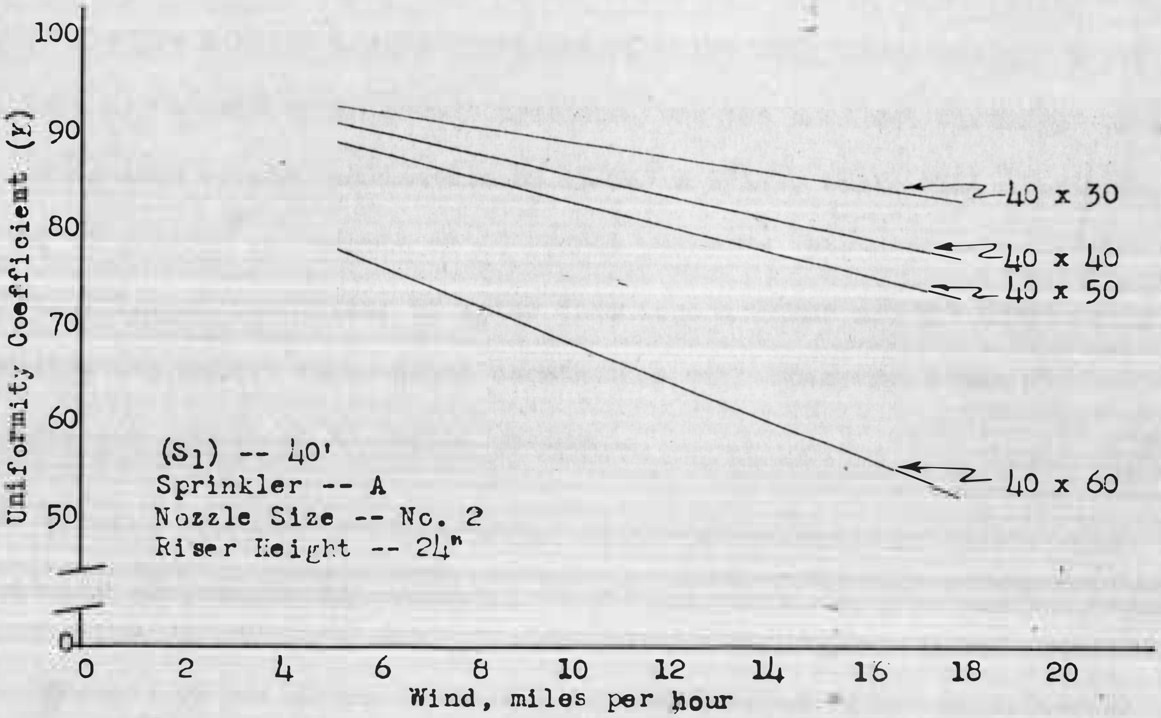

Figure 18. Uniformity for 56 Pound Pressure

However, there is a definite break between the higher pressures and the lower pressures. Figure 20 has like conditions as Figure 19 with the exception that a 40' x 40' spacing is used. The break in lines shows in this figure as is shown in Figure 20. A pressure greater than 56 pounds per square inch gauge would perhaps help to obtain an even better distribution pattern. The limiting factor would be the cost of operation of pumping. It is beyond the scope of this study to determine the maximum economical pressure.

Quantity of Water

To vary the quantity of water within one type of head, the nozzle size is changed. In this study three different size nozzle combinations were used within the medium weight sprinkler head with a 3/4" riser inlet. A 5/32" x 3/32" nozzle combination, which will discharge about six gallons per minute at 40 pounds pressure, was the smallest discharge used. A medium size nozzle combination of 13/64" x 5/32", which will discharge about 13 gallons per minute at 40 pounds pressure, was used as a standard. To check larger quantities of water discharge a 9/32" x 7/32" nozzle combination was used. This nozzle combination will discharge about 21 gallons per minute at 40 pounds pressure.

In this analysis all conditions, with the exception of nozzle size were kept as constant as possible.

Figures 21 and 22 are graphical representations of the pattern with the small nozzles at 40 pounds pressure. The medium weight head with a

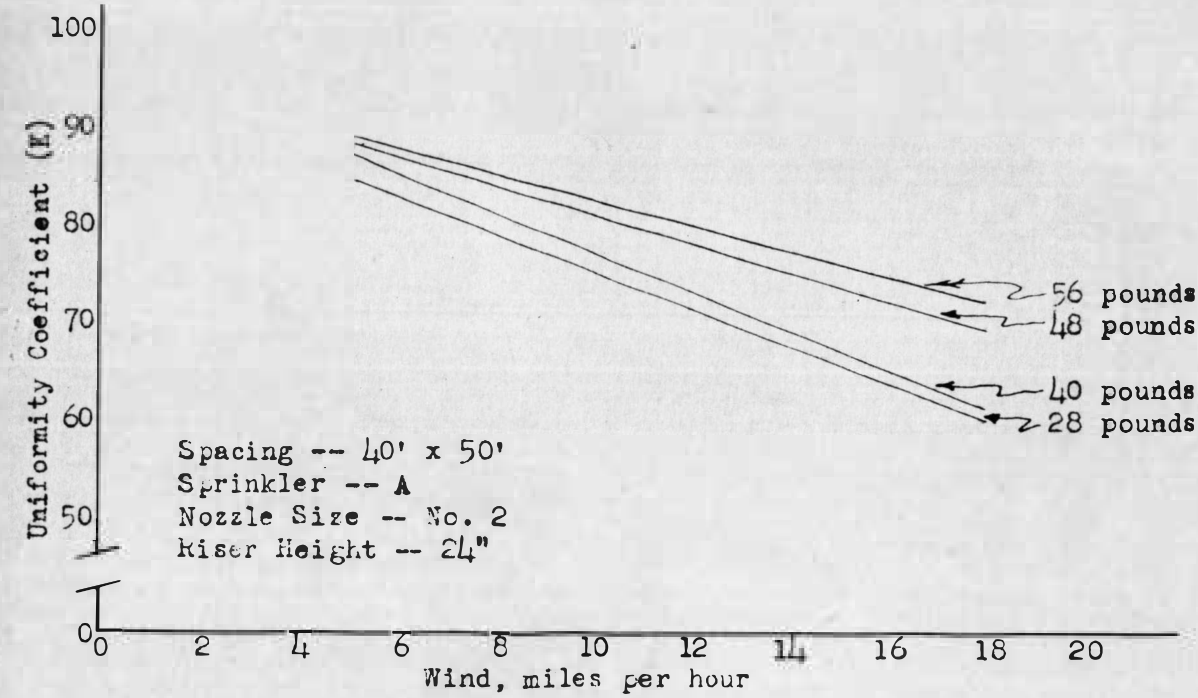

Figure 19. Comparison of Uniformity for Various Pressures.

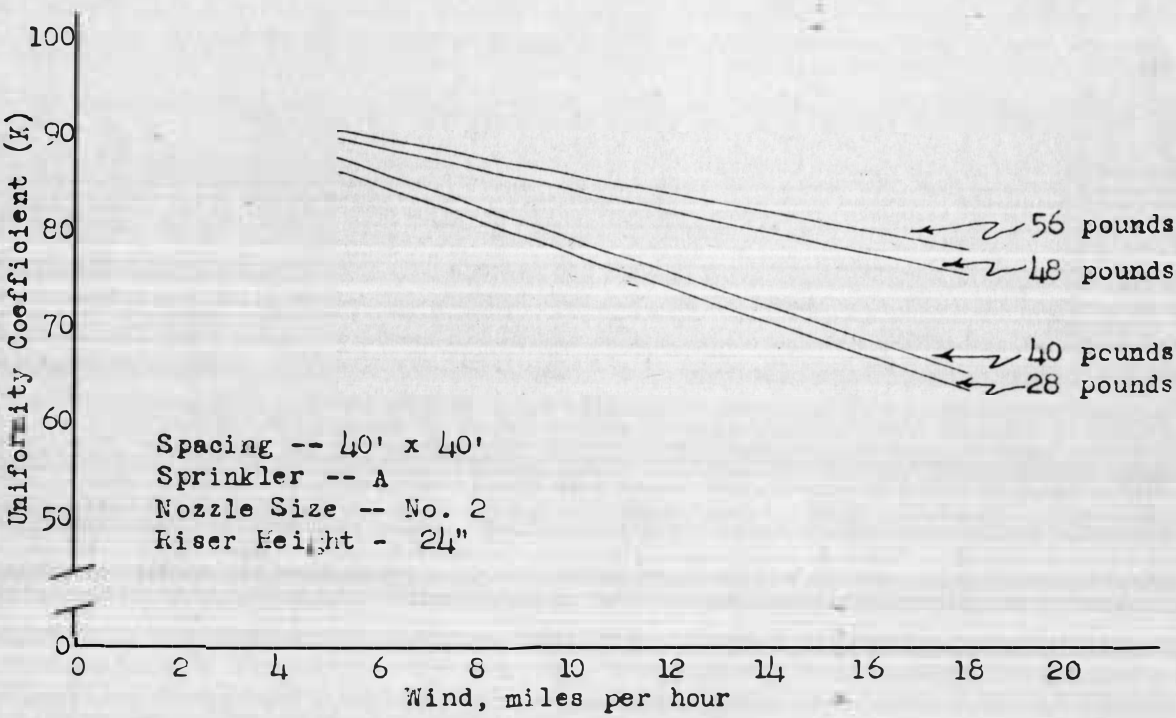

Figure 20. Comparison of Uniformity for Various Pressures.

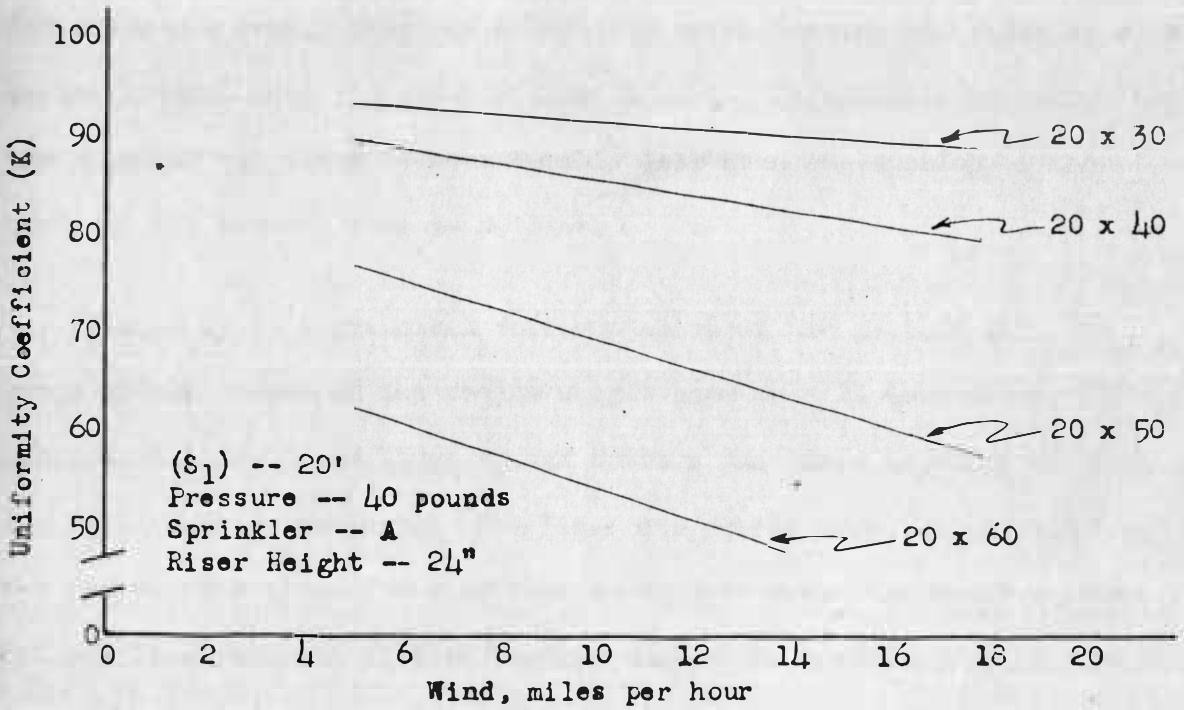

Figure 21. Uniformity for 5/32" x 3/32" Nozzle.

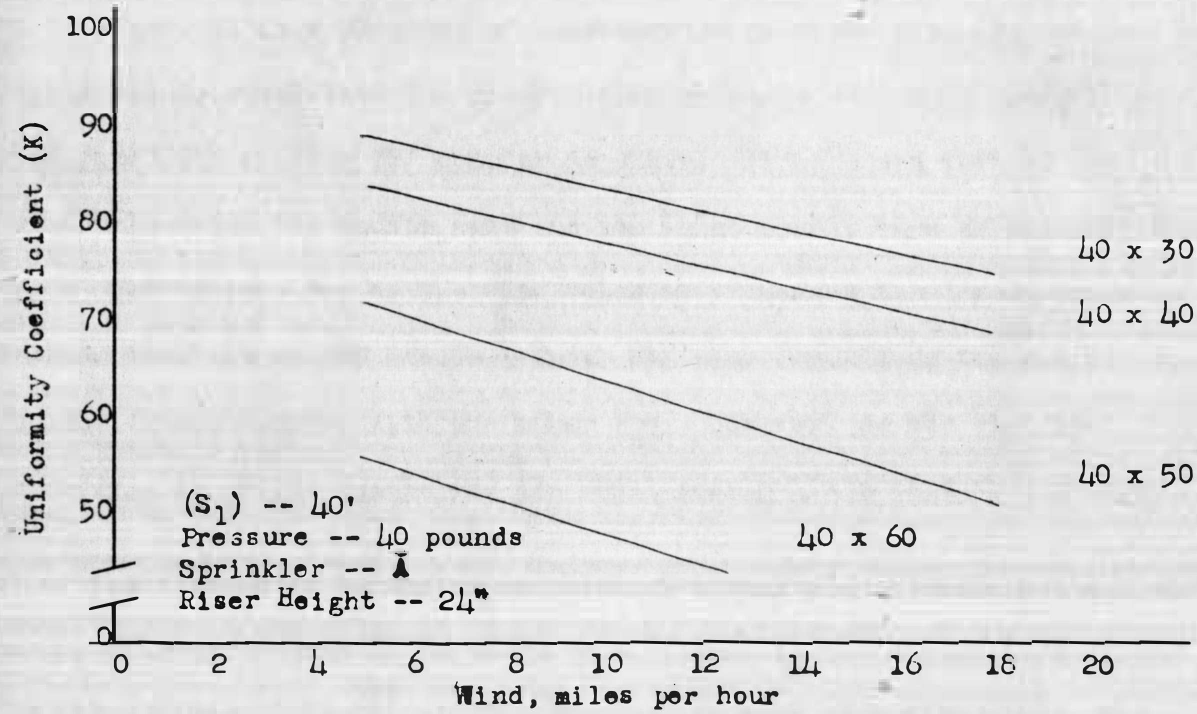

Figure 22. Uniformity for 5/32 x 3/32 Nozzle.

24" riser was used. There is a definite break between the lines as soon as the lateral move is greater than 40 feet. It can also be noted that the slope of the lines is considerably less when the spacing of the heads on the lateral line is 20 feet.

Figure 23 is a graphical representation of the pattern with the large nozzle placed on the medium weight head on a 24 inch riser. It is noted that there is no large spread between the lines as there is when the small nozzles are used. The lines are nearly parallel and not very far apart. The lines for a 20 foot spacing of sprinkler heads on the lateral line were not plotted because that close a spacing would make the precipitation rate greater than could be used under most actual irrigation conditions.

Figure 24 is a plotting of distribution patterns with all conditions nearly equal with the exception of nozzle size. A 40 pound pressure with a 40' x 50' spacing is shown. It is noted that at low wind velocities the medium size and the large nozzle have very nearly the same coefficient, but as the wind velocity increases the large nozzle is better than the medium nozzle. Under all wind conditions the small nozzle cannot compete with the other two. However, as the wind increases, the medium nozzle and the small nozzle lines tend to converge.

The difficulty in trying to obtain a better distribution pattern by using a larger nozzle is that the type of soil is the controlling factor in determining nozzle size. The greater the rate of infiltration, the

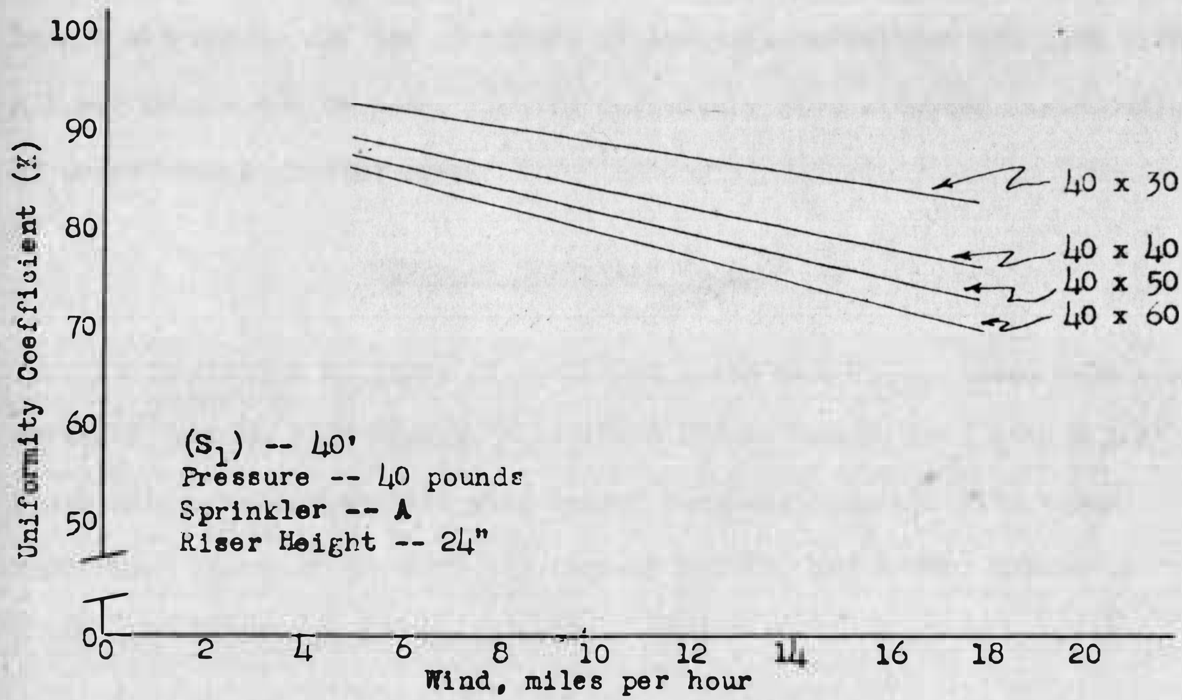

Figure 23. Uniformity for 9/32 x 7/32 Nozzle.

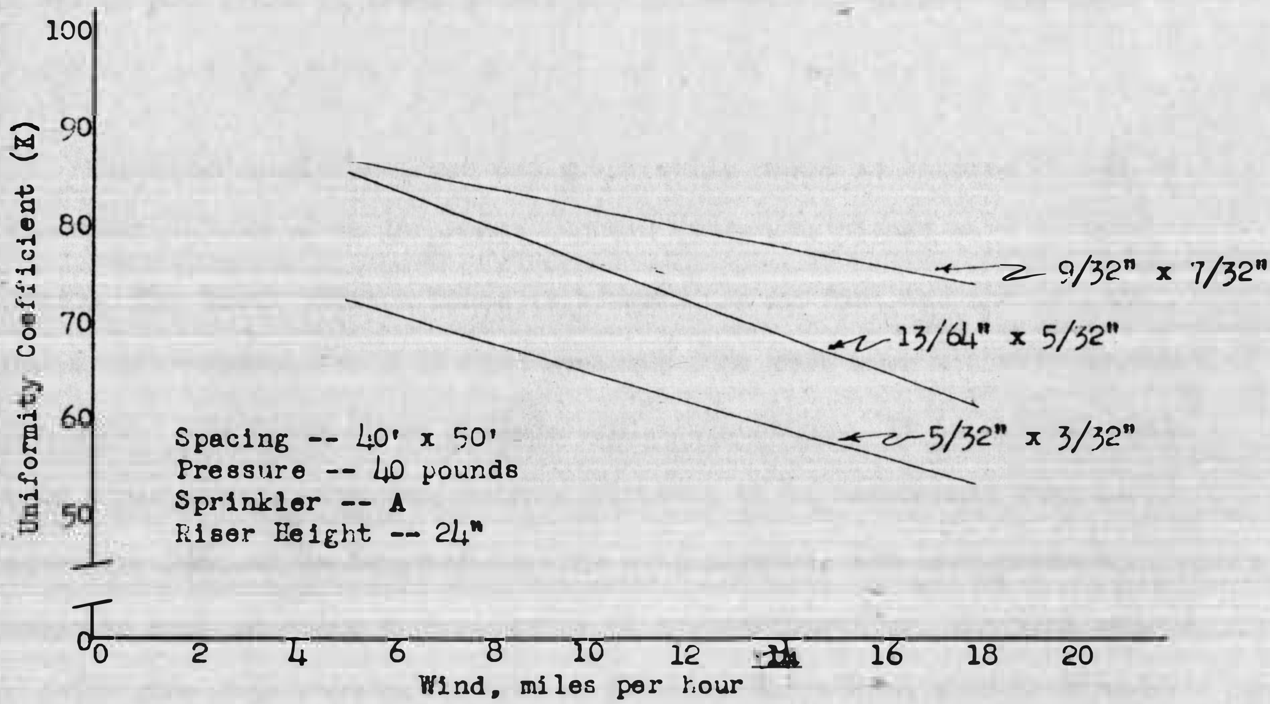

Figure 24. Comparison of Uniformity for Different Size Nozzles.

larger the nozzle may be. However, if the soil conditions are such that a large nozzle can be used, it will definitely give a better distribution of water over a greater area.

Type of Sprinkler Head

The variation in types of sprinkler heads within one trade name was narrowed down to four types: a standard medium weight head with a 3/4" riser inlet, a heavier head with longer nozzle inlets and with a one inch riser inlet, a low angle (7 degree) nozzle, and a wind nozzle in which only the range nozzle is used.

Figures 25 and 26 show the pattern lines at 40 pounds pressure of a low angle nozzle. A 24 inch riser was used. It can be noted that the slope of the lines is greater than for other type of heads. The break between lines is between the 40 foot and the 50 foot move.

The wind nozzle patterns are graphically shown in Figures 27 and 28. The nozzle pressure is 40 pounds and the heads are placed on a 24 inch riser. The break between lines is between the 50 foot and the 60 foot move. The pattern for a 40 foot move and a 50 foot move are very nearly the same. The lines cross at lower wind velocities. It is natural that they would cross. Checking back to Figure 5 it is noted that when a geometric pattern as is shown in Type D is plotted, the line makes a definite dip and comes back up again at a wider spacing. The wind nozzle gives a geometric pattern similar to Type D. Therefore, a 50 foot move can have a better pattern than a 40 foot move.

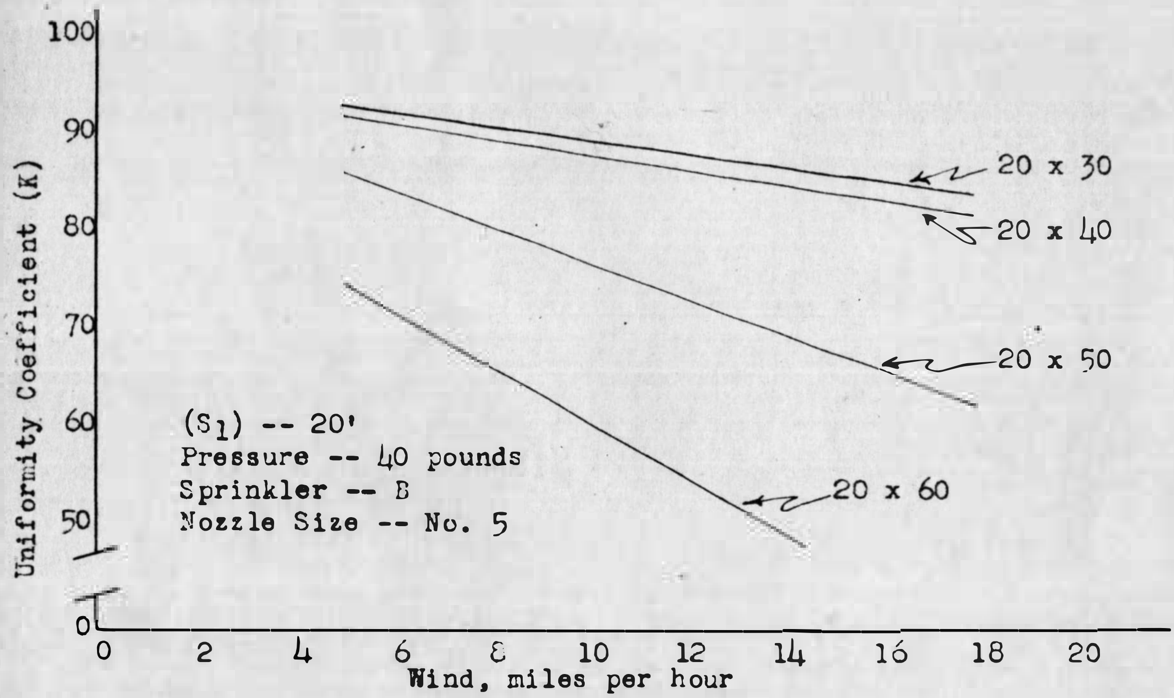

Figure 25. Uniformity for Low Angle Nozzle.

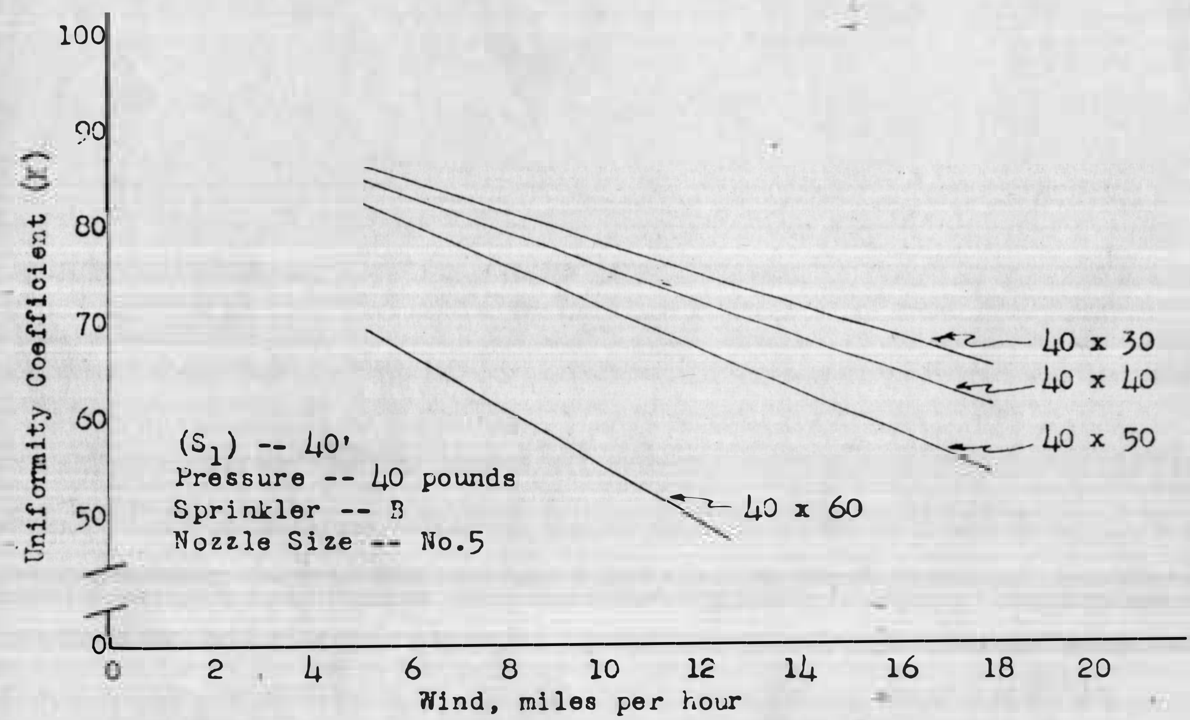

Figure 26. Uniformity for Low Angle Nozzle.

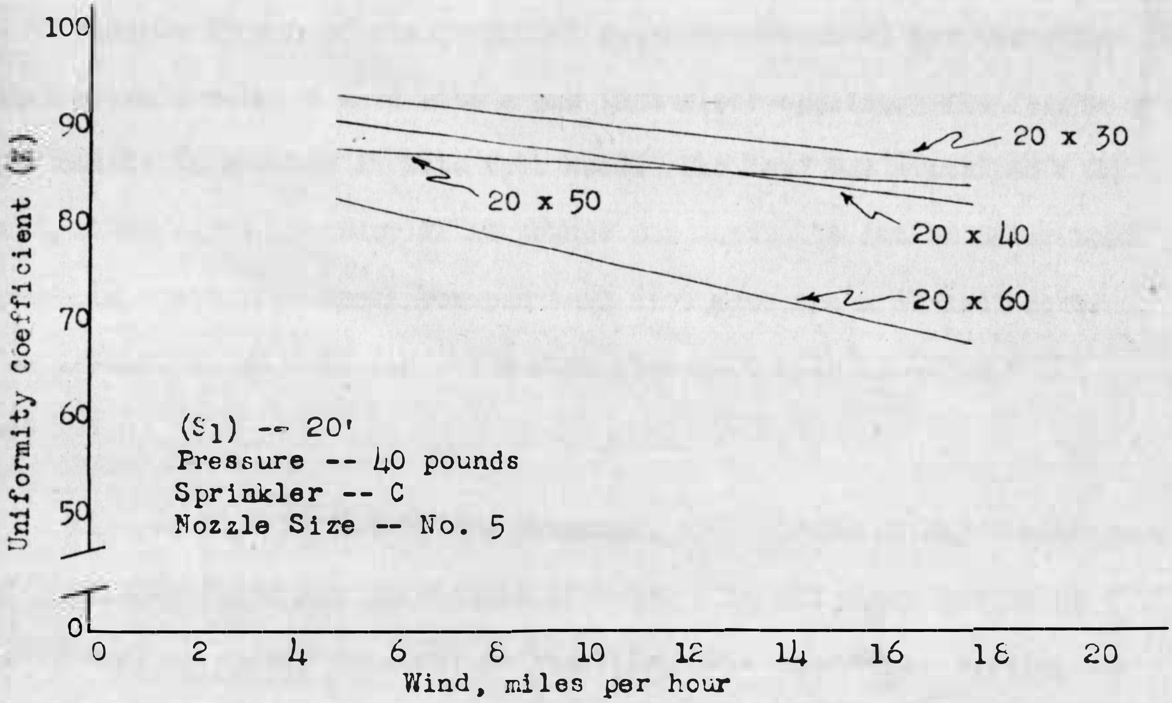

Figure 27. Uniformity for Wind Nozzle.

Figure 28. Uniformity for Wind Nozzle.

Figures 29 and 30 are graphical representations of the distribution pattern using a head with a one inch riser opening. The length of the nozzle is greater in this type head. The head was placed on a 24 inch riser and a pressure of 40 pounds was used. It can be noted that there is a definite break between a 50 foot move and a 60 foot move. The precipitation rate for the medium size head with 13/64" x 5/32" nozzles.

Figures 31, 32, and 33 are graphical comparisons of different types of sprinkler heads and quantities of water with all other variables being kept as nearly constant as possible. The closer the spacing between lateral moves, the less difference there is between different heads. The nozzle that discharged 21 gallons per minute in every instance has the best pattern for wind velocities of five miles per hour or greater. The higher the wind velocity the more difference there is present.

Figure 34 is a graphical representation of the distribution pattern using nozzle sizes and types with a spacing so as to obtain approximately the same rate of precipitation. The low angle nozzle, the 13/64" x 5/32" nozzle and the wind nozzle, all have spacing of 20 feet in the line with a lateral move of 50 feet. The large 9/32" x 7/32" nozzle has a spacing of 40 feet in the line and a lateral move of 50 feet. There would be the same amount of labor involved in moving the pipe if this were under actual irrigating conditions. The difference in the spacing used is in the spacing of the heads on the line. All heads have a riser height of

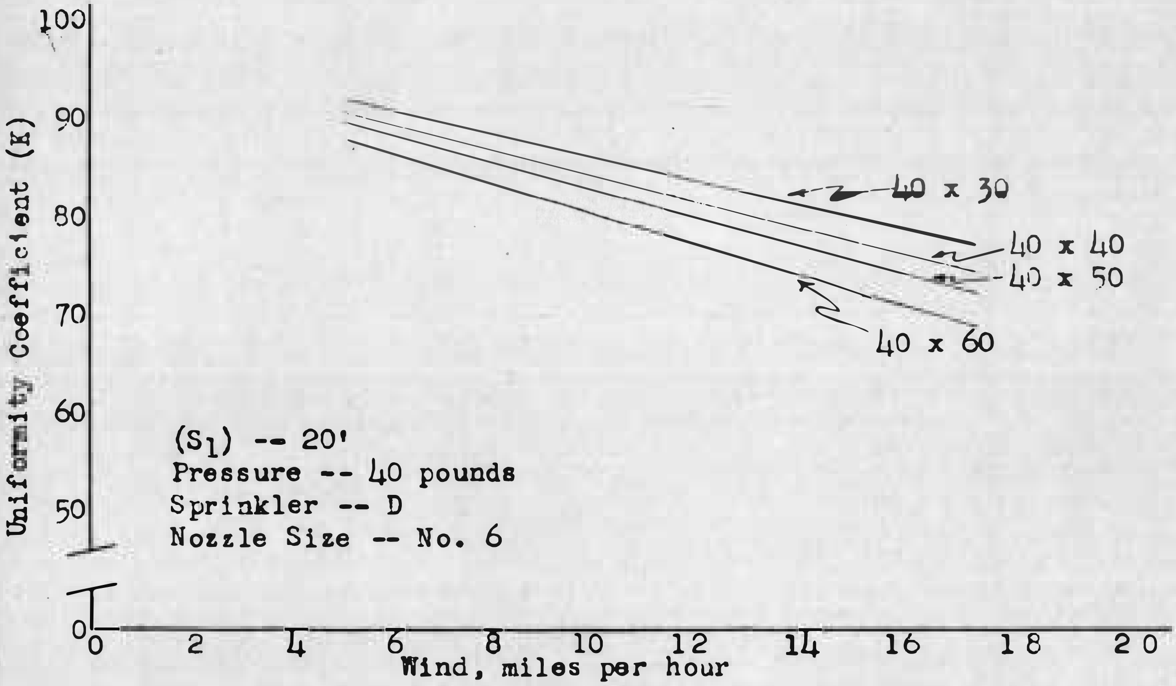

Figure 29. Uniformity for 1" Riser Outlet Head.

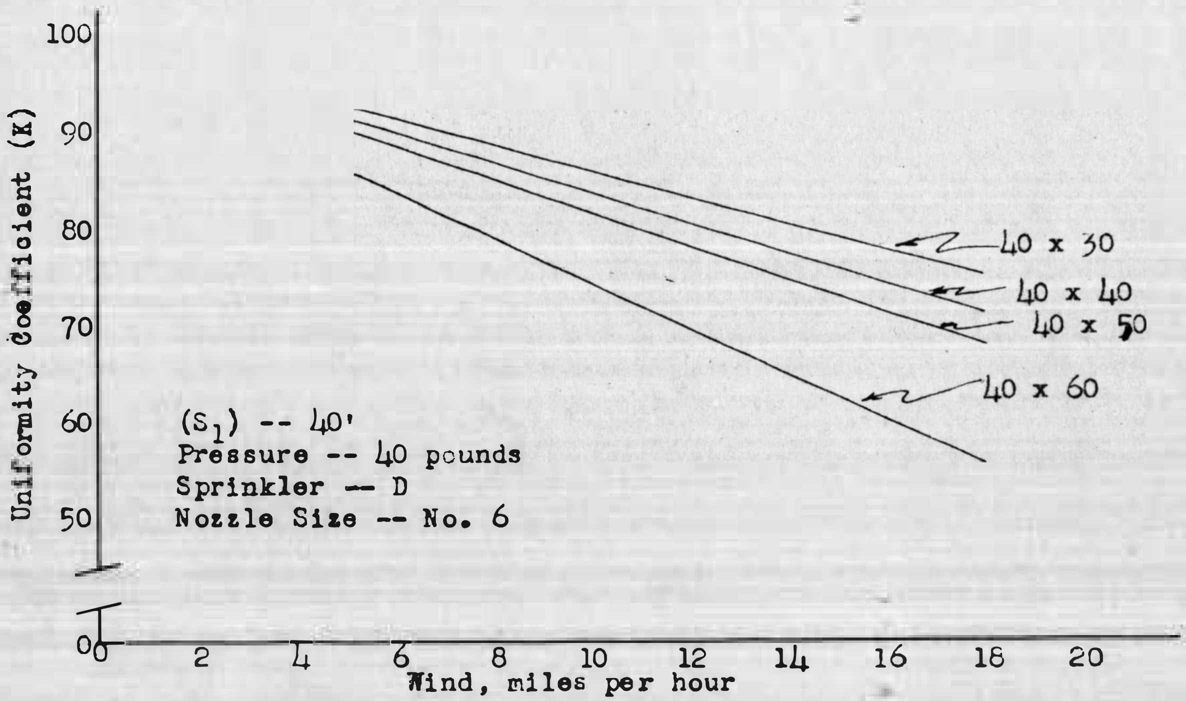

Figure 30. Uniformity for 1" Riser Outlet Head.

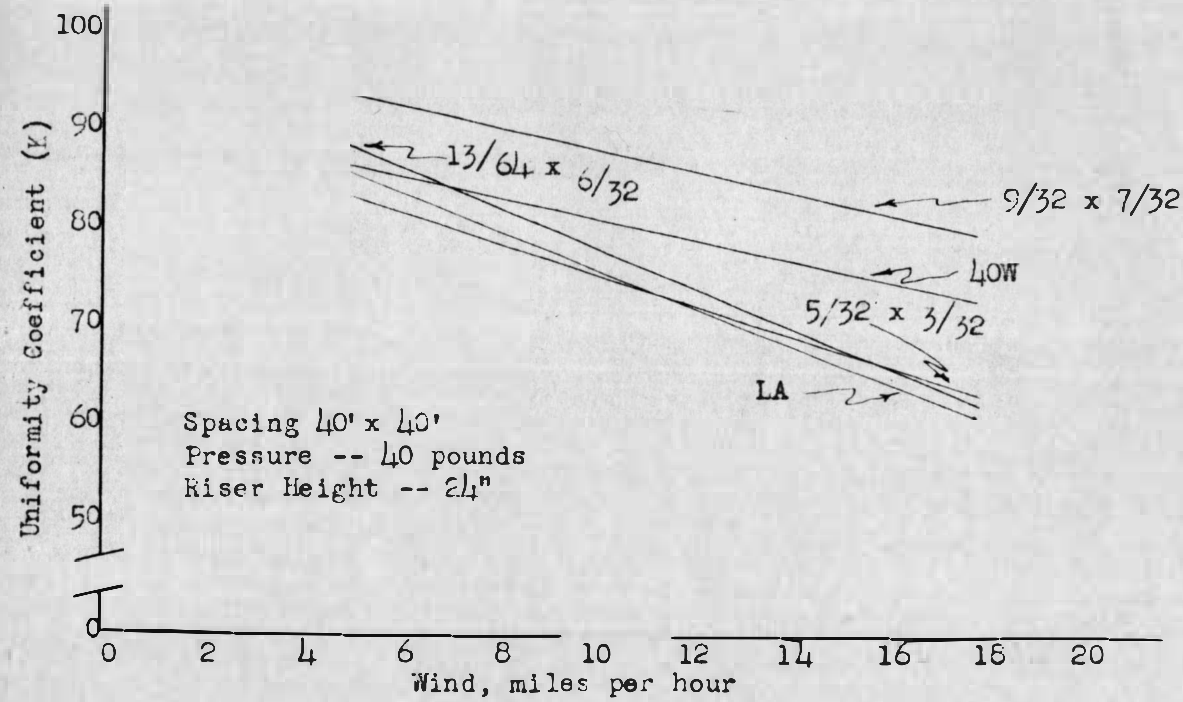

Figure 31. Comparison of Uniformity for Various Heads and Nozzles.

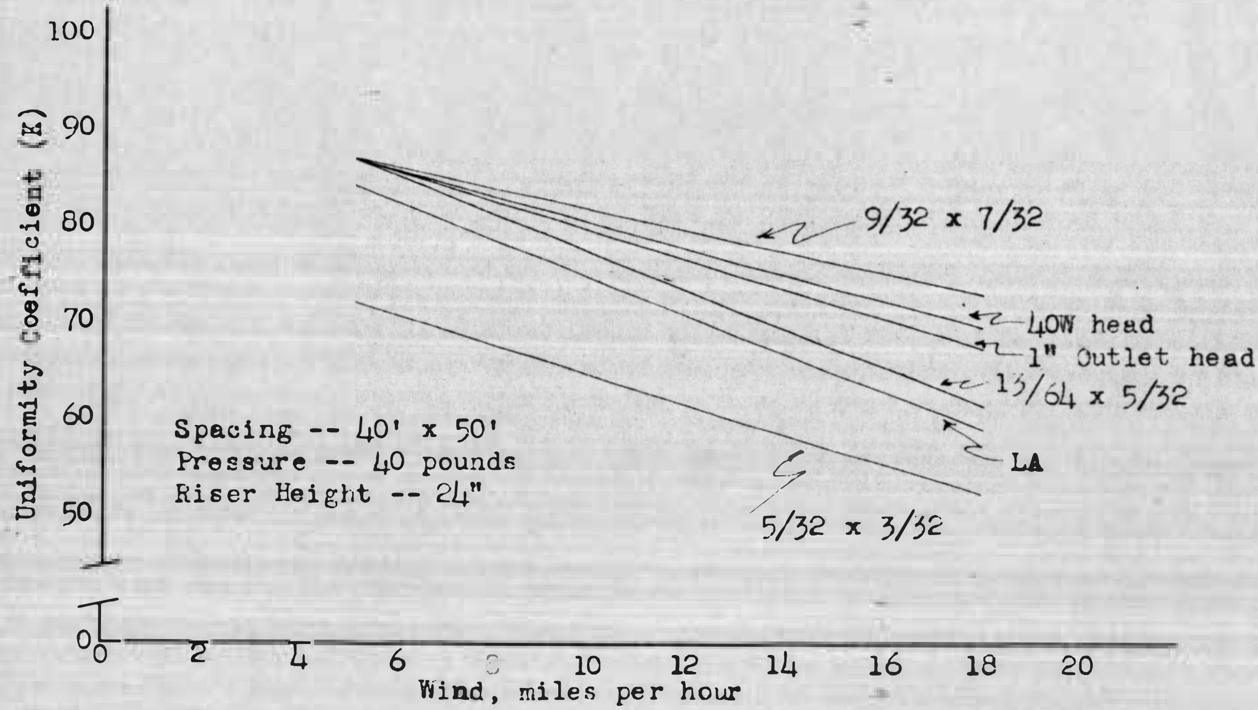

Figure 32. Comparison of Uniformity for Various Heads and Nozzles.

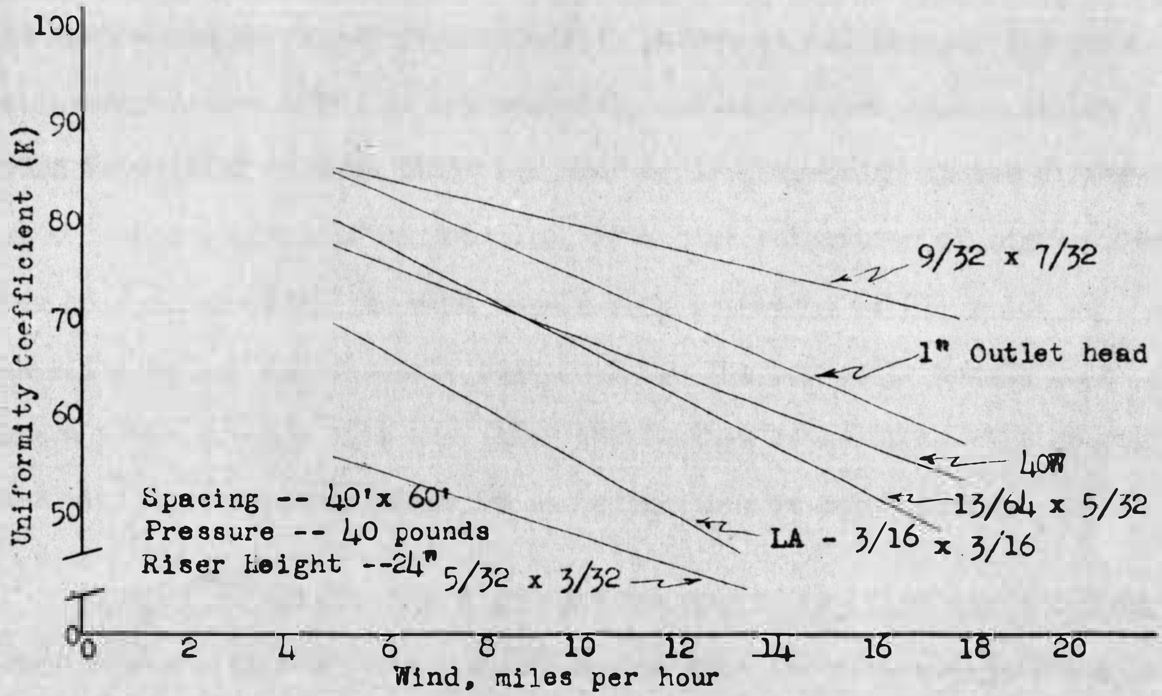

Figure 33. Comparison of Uniformity for Various Heads and Nozzles.

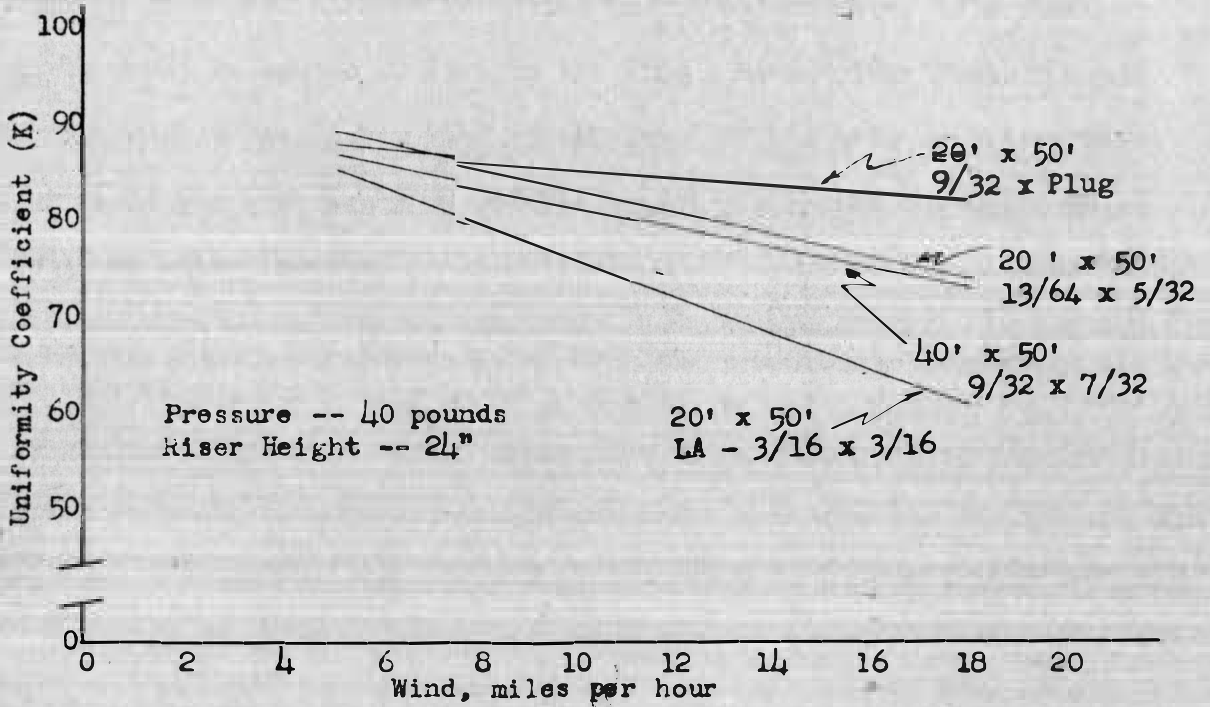

Figure 34. Comparison of Uniformity for Equal Precipitation Rate.

24 inches and the riser pressure is 40 pounds in all cases. The rate of precipitation would be approximately 0.9 inches per hour. At low wind velocities of four miles per hour or less there is little difference in the pattern of any nozzle. With wind velocities of eight miles per hour or greater, the wind nozzle with a spacing of 20' x 50' is superior to any other nozzle combination. The low angle nozzle line has a slope greater than any other combination of nozzles. The greater the wind movement the poorer it is in relation to other heads.

The larger nozzle with a 40 foot spacing in the line and a medium size nozzle with a 20 foot spacing in the line are very nearly identical. By having a 20 foot spacing in the line twice as many heads per lateral line would be required and the installation cost of a sprinkler system would be increased with no resulting benefits. However, if a wind nozzle would be spaced 20 feet in the line a much better pattern would be obtained in the higher wind velocities. If the wind were less than four miles per hour the wind nozzles cannot distribute the water as evenly as other types.

SUMMARY AND CONCLUSIONS

Sprinkler irrigation has been practiced for the last several decades. However, its use on other than specialized and garden crops has spread very rapidly during recent years.

Sprinkler systems have been designed in the past on the basis of a maximum wind velocity of four miles per hour or less. In this area the average wind velocity is approximately 10.8 miles per hour during the irrigation season. Unless original designs are modified poor irrigation efficiency is obtained.

The following factors, which can distort the distribution pattern were studied:

1. Wind velocity.
2. Angle of wind approach with respect to lateral line.
3. Type of sprinkler head.
4. Height of riser.
5. Water pressure at riser.
6. Quantity of water per sprinkler head.
7. Riser spacing in lateral line and between lateral lines.

In order to compare one test pattern with another the following formula was used:

$$K = 100\left(1 - \frac{\Sigma x}{m\,n}\right)$$

where K is the uniformity coefficient expressed as a percentage, x is the deviation of individual observations from the mean value m, and n is the number of observations.

It is concluded that:

1. Tall risers are superior to short risers.

2. Angle of wind with respect to lateral line has no effect.

3. There is a definite breaking point between a 50 foot move between lines and a 60 foot move between lines.

4. High pressures are superior to low pressures.

5. Large quantities of water per nozzle will result in better patterns than small quantities of water.

6. In winds of eight miles per hour or greater, a head with only the range nozzle in use exceeds results obtained by a head with both a range nozzle and a spreader nozzle in use.

7. A head with a large water capacity spaced 40 feet on the line is as good as heads with one-half the water capacity spaced 20 feet on the line.

In this study, distribution pattern was the only factor considered. Modifications of results may have to be made to overcome other factors such as soil crusting, evaporation losses, labor schedules, rates of soil infiltration, size of water supply, type of equipment available, and the types of crops grown.

Time limited the number of tests that could be made. More tests to confirm the results that were obtained should be made before the above conclusions can be made definite statements.

A P P E N D I C E S

Appendix A — Example of Field Notes*

Date 8-26-49

Run Number 92

Starting Time 9:45 a.m.

Pump pressure 60#

Stopping time 10.45 a.m.

Riser pressure 42#

Wind direction S 40° W, S 40° W, S 35° W, S 40° W

Riser height 24 inches

Sprinkler head Type A.

Nozzle size 9/32" x 7/32"

Wind velocity 10.3 m.p.h

Revolutions 1 1/2 r.p.m

Direction of lateral South

Weather Fair & Warm

Comments Run same time as run 91
Conditions favorable

Jlw

sprinkler head

						8 1!									
6	20	34	60	78	104	112	92	108	100	84	56	40	24	15	8
6	20	34	50	64	77	74	92	58	70	56	44	36	24	15	11
8	22	44	50	67	62	56	60	44	42	40	39	34	24	16	12
10	24	48	66	69	68	56	58	42	36	37	39	38	38	18	11
8	28	56	76	73	72	58	54	55	49	56	50	44	28	16	8
8	26	58	82	95	78	73	55	82	76	76	66	52	30	14	4
6	24	54	85	100	79	96	78	102	88	82	72	54	32	19	2
6	22	42	80	107	89	116	118	118	92	84	70	48	28	16	2

sprinkler head

*Copied from Page 94 of original notes.

Appendix B and C.

Summary Sheet

Pattern

112	92	108	100	96	76	74	84	93	112						
74	92	58	70	62	64	70	74	79	88						
56	60	44	42	48	61	78	74	83	74						
56	58	42	36	47	63	86	104	87	79						
59	54	55	49	64	78	100	104	89	80						
73	55	82	76	78	92	110	112	109	82						
96	78	102	89	88	96	108	117	119	81						
116	118	118	92	90	92	90	108	123	91						

30	10	26	18	8	6	8	2	11	30						
8	10	24	12	20	18	12	8	3	6						
26	22	38	40	34	21	4	8	1	8						
26	24	40	46	35	19	4	22	5	3						
24	28	27	33	18	4	18	22	7	2						
9	27	0	6	4	10	28	30	27	0						
14	4	20	6	6	14	26	35	37	1						
34	36	36	10	8	10	8	26	41	9						

Spacing 40' x 60'

m 82

n 80

Sum(Σ) 6561

Σ x (dev) 1401

K 78.6

Run no 92

Wind Vel. 10.3

Wind Dir 40°

R. Pressure 42

R Height 24

S. Head A

Nozzle 9/32" x 7/32"

APPENDIX D. SAMPLE CALCULATIONS OF FORMULAE USED IN TABLE X

Spacing 40' x 60' Pressure 40 pounds

Wind Velocity X	Uniformity Y	X^2	Y^2	XY
11.7	62.4	136.89	3893.76	730.08
7.9	73.6	62.41	5416.96	581.44
10.2	70.6	104.04	4984.36	720.12
1.5	89.1	2.25	7938.81	133.65
7.9	68.1	62.41	4637.61	537.99
9.6	70.1	92.16	4914.01	672.96
5.2	75.6	27.04	5715.36	393.12
6.0	78.5	36.00	6162.25	471.00
7.0	70.3	49.00	4942.09	492.10
7.1	75.1	50.40	5640.01	533.21
15.5	48.4	240.20	2342.56	750.20
10.7	72.6	114.50	5270.76	776.82
14.7	51.8	216.10	2683.24	761.46
115.0	906.2	1193.40	64541.78	7554.05

$$a = \frac{N \cdot XY - X \cdot Y}{N \cdot X^2 - (X)^2} = \frac{13(7554) - 115(906)}{13(1193) - (115)^2} = \frac{98,189 - 104,190}{15,509 - 13,225}$$

$$a = \frac{-6001}{2284} = -2.63$$

$$b = \frac{X^2 \cdot Y - X \cdot XY}{N\ X^2 - (X)^2} = \frac{1193(906) - 115(7554)}{13(1193) - (115)^2} = \frac{1,080,858 - 868,595}{15,509 - 13,225}$$

$$b = \frac{212,263}{2284} = 92.93$$

$$Y = b + aX = 92.93 - 2.63X$$

$S_x^2 = 176.10$
$S_y^2 = 1372.67$
$S_{xy} = 453.00$

$$r = \frac{S_{xy}}{(S_x^2)(S_y^2)} = \frac{453.00}{(176.10)(1372.67)}$$

$r = 0.919$

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